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THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on 1 May 1957, the Chair being taken by H. Hyams, a vice-president of the Institute.

The minutes of the previous meeting were read, confirmed, and signed as a correct record. The names of members elected since the previous meeting were also announced.

The Chairman said: In to-night's proceedings there are two papers, "The Properties of Asphaltic Bitumen in Relation to its Use in Road Construction," by Dr A. R. Lee and J. H. Nicholas, and "Hot Asphalt Construction," by P. C. Leaver.

Introducing the authors, Mr Hyams said that Dr Lee was Deputy Director of Road Research, dealing with materials and methods of construction, having been at the Road Research Laboratory since 1932. He was chairman of many committees on bituminous materials and the author of many papers on the subject.

Mr Nicholas joined the staff of the Road Research Laboratory in 1941, and in 1956 became head of the Bituminous Materials Section of that laboratory. Papers published by him include descriptions of research on the oxidation of tar oils and on the adhesion of bituminous materials.

Mr Leaver, Contracts Manager of the Asphalt Department of George Wimpey and Co. Ltd, has been concerned with the technical and commercial supervision of all types of asphalt construction, both in the U.K. and overseas, for the last six years.

The following papers were then presented in summary.

THE PROPERTIES OF ASPHALTIC BITUMEN IN RELATION TO ITS USE IN ROAD CONSTRUCTION *

By A. R. LEE † and J. H. NICHOLAS †

SUMMARY

The principal properties of bitumen which influence the performance of road surfacing materials in which it is used as a binder are its rheology, adhesive characteristics, and durability.

The deformation of asphalt under heavy traffic at high road temperatures depends primarily on the amount and viscosity of the bitumen. If a durable asphalt of relatively high bitumen content is stipulated, adequate resistance to deformation necessitates the use of a bitumen of high viscosity. Other methods of obtaining high stability may lead to loss of durability. The fracture of an asphalt at low road temperatures involves both the elastic and the viscous properties of the bitumen, and the concept of "stiffness," which includes both these factors, helps in the prediction of the likely behaviour of an asphalt under brittle conditions.

Problems of the adhesion of bitumen to roadstone generally arise only in the presence of water. The preferential affinity of roadstone for water may lead to premature failure of a bituminous surfacing. This is particularly true of surface dressings, but research has shown how such failures may be eliminated by the use of suitable surface-active agents, used as indicated by a simple laboratory test. Stripping in coated macadam or fine cold asphalt can also be minimized by using hydrated lime or Portland cement as part of the filler, together with a suitable acidic material in the bitumen, or by the use of surface-active agents of the type found suitable for surface-dressing work. A stripping test has been developed which so far shows good correlation with road performance.

The durability of a bituminous surfacing depends to a great extent on the binder content, but the tolerance in binder content between disintegration and deformation and slipperiness depends on the intrinsic resistance of the bitumen to weathering. The bitumens generally available in the U.K. have a reasonable or high resistance to weathering, and macadams made to correct composition are generally very durable. Too high a resistance to weathering is a disadvantage in a bitumen used in a dense asphalt: a non-skid surface is more easily obtained when some weathering occurs. It is probable that the weathering is due primarily to atmospheric oxidation, and non-skid asphalts have been produced by incorporating an oxidizable material in bitumen of high resistance to oxidation. Further research on weathering is desirable so that a reliable durability test is made available.

INTRODUCTION

VERY large quantities of bitumen are used every year throughout the world in the construction and maintenance of road surfacings. This bitumen is not a uniform material; its properties vary greatly, depending on the crude source. The conditions under which it is used also vary over a very wide range of climate and traffic; furthermore, there are many different types of road material in which bitumen is used as the binder, these types being intended to serve different purposes.

In all these conditions, however, the bitumen binder has the function of acting either as the principal constituent of a mortar which must withstand the mechanical forces imposed by traffic, or as an adhesive which resists the combined action of traffic, weather, and time. The principal properties of the bitumen of interest to the roadmaker are therefore its rheological characteristics, adhesive properties, and durability.

Although a few thousand tons of petroleum oil are now obtained each month from wells in the U.K., all the bitumen used here has its source abroad, and

* MS received 12 March 1957.

† Road Research Laboratory, D.S.I.R., Harmondsworth, Middlesex.

the bitumen so available is limited to very few types. These types have generally been very satisfactory for use in roads and although road engineering in the U.K. has accordingly benefited, the lack of variety has limited our direct knowledge of the road behaviour of different bitumens and has tended to restrict the scope of research.

RHEOLOGY

The two properties of bituminous road surfacings that are affected by the rheological properties of the bitumen binder are the tendency to deformation or flow, particularly under heavy traffic at high road temperatures, and the possibility of fracture at low temperatures.

Bitumen macadam is not generally liable to deformation because, when well compacted, the internal friction due to stone-to-stone contact is adequate for resisting most traffic stresses. With dense mixtures, however, internal friction is reduced and may become zero for voidless mixes, and so the preparation of a durable dense surfacing material gives rise to the risk of deformation.

Cracking of asphalts is not generally a problem in the U.K. under normal traffic conditions unless there is movement in the foundation such as the deflection at joints and cracks in a concrete base or the elastic or permanent deformation of the subgrade beneath an under-designed road structure. The ultimate failure of a bitumen macadam by fretting or disintegration and the loss of stone from a surface-dressing are also due to fracture of the bitumen or of the bitumen–aggregate bond at low temperatures under traffic stresses.

Deformation of a dense asphalt depends to a considerable degree on the amount and viscosity of bitumen in the mixture. Although a high stability is obtained by using low binder contents, mixtures so designed are liable to be permeable and susceptible to weathering, and are less durable than others. The range of binder contents between the point at which durability is reduced and that at which the risk of deformation occurs depends largely on the properties of the bitumen. If the bitumen were extremely resistant to the action of weather, low binder contents could be tolerated for asphalts to be laid on stable foundations, and deformation problems could thus be minimized. However, as impermeable mixtures are desirable with normal bitumens so as to exclude air and water, the rheological properties of the bitumen will be of great importance in the problem of obtaining adequate resistance to deformation.

The principal property of bitumen which affects the rheological behaviour of asphalt is its viscosity. Experience shows that an increase in the viscosity of the bitumen leads to a marked increase in the resistance to deformation of the asphalt. Bitumens vary considerably in their flow characteristics, and there is a considerable amount of literature on the subject. In general, they show a deviation from Newtonian flow in that the viscosity falls as the shear stress or the rate of shear is increased, and they possess some degree of elastic recovery. One result of these characteristics is that bitumens having the same penetration may have significantly different viscosities when measured at low stresses. Some examples are given in Table I for bitumens all having a penetration of 65.

To a first approximation the relation between D (rate of shear) and S (shearing stress) can be expressed by the empirical relation

$$D = \frac{1}{\eta} S^p$$

The greater the deviation from Newtonian flow, the greater is the value of the index p (the plastic flow index). The data in Table I also show the large reduction in viscosity produced by a rise of 15° C. If a dense asphalt is subjected to a constant stress, flow occurs, which is at first rapid and then reaches a constant rate for some limited amount of deformation. The relation between this rate (R) and the applied stress (S) can be also expressed by an equation

$$R = KS^p$$

TABLE I

Viscosity of 65 Penetration Bitumens

Type of bitumen	Viscosity (poises) at shear stress 3000 dynes/sq. cm.		Plastic flow index, p
	At 25° C	At 40° C	
Californian	$1{\cdot}70 \times 10^6$	$4{\cdot}87 \times 10^4$	1·02
Venezuelan	$2{\cdot}64 \times 10^6$	$9{\cdot}1 \times 10^4$	1·10
Mexican	$3{\cdot}92 \times 10^6$	$14{\cdot}3 \times 10^4$	1·22
Fluxed blown Mexican	$22{\cdot}1 \times 10^6$	$57{\cdot}9 \times 10^4$	1·44
Trinidad A.C.	$4{\cdot}66 \times 10^6$	$15{\cdot}9 \times 10^4$	1·20
Cuban A.C.	$44{\cdot}7 \times 10^6$	$84{\cdot}1 \times 10^4$	—

It is found that not only is the plastic flow index of the asphalt greater when it is made with the bitumens which have the more pronounced plastic flow, but asphalts made with such bitumens also show greater resistance to deformation. For example, the flow of the asphalt made with a 65 pen Californian bitumen is about 10 times that made with a Mexican bitumen.

On this basis one might expect the best results for resistance to deformation to be given by asphalts made with blown bitumens having a large plastic flow index. This prediction has not yet been confirmed on the road, although a road experiment in Scotland has shown that such an asphalt is considerably less durable than those made with less plastic bitumens. The reason for this is not known.

Over a considerable temperature range there is a straight line relation between log viscosity and log temperature Fahrenheit. A similar relation also

exists between the log of the rate of deformation of an asphalt and the log temperature: the slope of this line, which is a measure of the temperature susceptibility of deformation of the asphalt, is the same as the slope of the line for the bitumen binder in the asphalt.[1] The high temperature coefficient of viscosity of bituminous binders thus explains why deformation can be a serious problem at high road temperatures.

A graphic illustration of the effect of temperature on the deformation of asphalt is given by the results of tests on the Laboratory's small road machine[2]; to obtain a given deformation at 30° C required 15 times more wheel-passes than at 45° C. It is for this reason that in the north of the country, where maximum temperatures are appreciably lower than in Southern England, stable asphalts can be made with bitumens of a lower viscosity and with a higher content of a bitumen of a given viscosity grade.

As long life requires a relatively high bitumen content for the asphalt, high resistance to deformation with such mixtures can be obtained only by the use of high viscosity bitumens. This is the technique adopted in the U.K., as exemplified by the mixtures specified in B.S. 594. For country roads a penetration of 60–70 is used; for city roads and other roads of high traffic intensity bitumen of 40 pen is used: the trend is towards the use of harder bitumens than formerly so as to cater for the ever-increasing weight of traffic. The asphaltic concrete commonly used in America is made with an aggregate having a continuous grading and a smaller quantity of a softer bitumen. The life of such asphalt is reported to be less than the life of asphalt used in the U.K.; certainly cracked asphalt on American roads is quite a common phenomenon. Such a grading leads to a smaller tolerance being permissible between low durability and excessive deformation.

The significance of the elastic properties of a bitumen for the deformation of asphalt is not at present apparent. Lee and Markwick[3] and Nijboer[4] have shown that in dense bituminous surfacings made with unmodified binders a delayed elastic recovery can occur when small strains have been imposed, even though the binders themselves show little or no elastic recovery. This recovery may be of some significance on the road under the normal transient loading. It is possible to impart marked elastic properties to bitumen by dispersing in it certain polymers, including natural rubber, but it is not yet known to what extent these properties affect the resistance to deformation at high road temperatures of an asphalt made with such binders. On the other hand, it has been shown that the pronounced elasticity produced by the incorporation of rubber imparts to the bitumen improved resistance to fracture; asphalt made with rubberized bitumen is also more resistant to fracture.

Fracture of an asphalt also depends to a major degree on the "viscosity" of the bitumen used, but under conditions of fracture the strains occurring will be small and the bitumen will not be behaving as a simple liquid. The elastic properties of normal bitumens are much more marked at these hardnesses than at low viscosities, and the concept of "stiffness" developed in recent years by van der Poel and his co-workers at Amsterdam[5] is of assistance in considering the behaviour of bitumens in the range where fracture may occur. When a bituminous binder is subjected to a constant tensile stress, deformation takes place, the strain increasing with time, but not necessarily at a uniform rate. The "stiffness" of the binder is defined by van der Poel as the ratio between the tensile stress and the total amount of strain which occurs. This ratio will obviously depend on the time for which the stress acts; in fact, stiffness is a decreasing function of time. The concept of stiffness has been applied over a wide range of times of loading: for very short times dynamic loading techniques have been used. One advantage of this concept is that with bituminous binders of a wide range of types the stiffness is independent of stress, to a first approximation. It will be noted that the stiffness compounds together the elastic and viscous characteristics of the binder. When stiffness is plotted as a function of time, differences in hardness or in temperature result for bitumens of the same penetration index in curves of the same shape, displaced in a direction parallel to the time-axis in conformity with the relationship:

$$\text{Stiffness} = f(\text{time} \cdot e^{A \cdot \text{temp}})$$

where A is a constant.

It follows that if the Ring and Ball Softening Point and Penetration Index of any bitumen are known, its stiffness can be calculated for different temperatures and different times of loading; van der Poel has constructed a nomograph to simplify this calculation.[5] The application of the concept of stiffness to the fracture of bituminous binders may be made using the relationship:

$$\text{Stress} = \text{Stiffness} \times \text{Strain}$$

If the stress is equal to or greater than the tensile strength of the bitumen, then fracture will occur. It has been shown that the tensile strengths of all (unmodified) bitumens are approximately the same, the value being about 30 kg/sq. cm.[6-8] It follows therefore that the stiffness will give an adequate indication of the tendency to fracture under given conditions. It will be appreciated, however, that factors such as fatigue, damping, and non-uniformity of stress conditions will complicate this simple relationship.

Thus, without undertaking fracture tests, the results of which are difficult to reproduce, it is possible to obtain a good indication of the likely behaviour of a given bitumen under conditions where fracture may be a problem.

When bitumen is used in a dense mixture, van der

Poel has found that the stiffness of the mixture is dependent only on the stiffness of the bitumen and its volume concentration; it is independent of the grading of the aggregate. These relationships are claimed to hold for all mixtures containing up to 85 per cent of total aggregate, to a sufficiently good approximation for engineering purposes.[9] The degree to which stiffness can be used to predict the fracture behaviour of a mixture must, however, be limited by the facts that:

(1) the aggregate itself fractures under brittle conditions;

(2) with a high volume-concentration of aggregate, as in most rolled asphalts, non-linear effects become increasingly important; and

(3) the bitumen in such mixtures is distributed in thin films in which complicated stress patterns will be developed.

Research has shown that the strength characteristics of materials in thin films may be very different from those in bulk; it has also been shown that, for bitumens in threads, reduction in cross-sectional area leads to a marked increase in strength.[8] The tensile strengths of asphalts have been measured, and it is clear that differences do appear, depending on the composition of the material. The addition of filler in particular leads to a marked change in breaking strength.[7, 8] Strengths of the order of 50 kg/sq. cm. have been obtained for sand asphalts; with a high filler content, strengths up to 100 kg/sq. cm. may be obtained. Nevertheless, for a given aggregate composition and a given binder content, the relative brittle properties of asphalts made with different bitumens can be assessed from a knowledge of the stiffness of the bitumen. The effect of binder content and of aggregate type and grading is much more complex, and further research on these points is required. Van der Poel suggests that to avoid brittle fracture the mixture should have a stiffness not exceeding 10^5 kg/sq. cm. at the lowest road temperature likely to be experienced.[9]

So far, the effect of the addition of polymers, such as natural or synthetic rubbers, on the stiffness of bitumen has not been indicated. It is unlikely that bitumens modified in this way will conform to the pattern evolved for unmodified bitumens. It has been shown [10] that the addition of natural rubber to a bitumen increases its viscosity, the resulting material having substantially improved brittle characteristics compared with a bitumen of the same viscosity. These effects are also imparted to an asphalt in which the modified bitumen is used. The type of effect obtained is illustrated graphically in Figs 1 and 2; in these figures extensibility indicates the degree to which the material can be stretched before fracture. It is not yet known whether these effects are reflected in improved durability of bituminous materials on the road in normal circumstances, although full-scale road experiments are in progress on the use of rubberized bitumen in surface dressing, coated macadam, and rolled asphalt. On the other hand, where particularly high strains occur, such as in an asphalt over a concrete joint where the concrete slabs

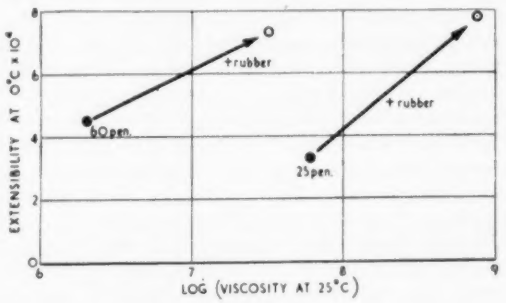

FIG 1

EFFECT OF RUBBER ON THE VISCOSITY AND EXTENSIBILITY OF BITUMENS

are moving relatively, both horizontally and vertically, it has been shown that a mastic asphalt containing a rubberized bitumen does not crack in circumstances where normal mastic has cracked. For this specialized application, high rubber contents (up to 15 per cent of the bitumen) are needed; such a concentration would be economically difficult to justify for normal surfacing purposes.

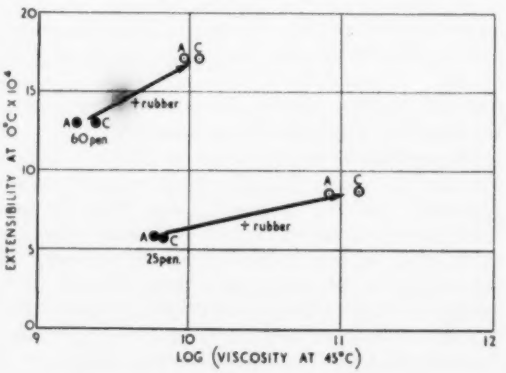

FIG 2

EFFECT OF RUBBER ON THE VISCOSITY AND EXTENSIBILITY OF SAND ASPHALTS

One of the principal difficulties with polymer-treated bitumen is that the effects of adding the polymer vary considerably with the time of heating, both during the incorporation of the polymer and in subsequent processing. This effect is illustrated in Fig 3, which also shows the effect of varying percentages of natural rubber on the impact strength of bitumen, as measured by a simplified Izod technique.

Asphalt may also fail in tension, not by a sharp fracture, but by prolonged weakening of the structure under a load lower than the brittle strength, which ultimately leads to rupture. This effect, first described by Lee, Reiner, and Rigden,[11] is associated with a steady increase in the volume of the asphalt as it deforms. The failure is due, not to a brittle fracture of the binder, but to the flow of the binder under the conditions of stress. This type of rupture is much more probable at temperatures above those at which brittle failure may occur. Rupture, in an asphalt, may therefore be of two distinct types: a brittle fracture under high rates of strain at low road temperatures, or a dilatant fracture under low rates of strain, usually at higher road temperatures.

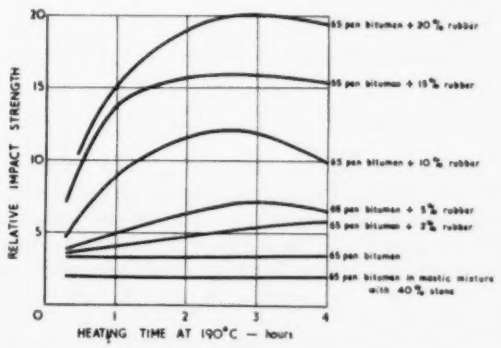

FIG 3

EFFECT OF HEATING TIME ON IMPACT STRENGTH OF MASTIC ASPHALTS (87% LIMESTONE POWDER, 13% BINDER) WITH VARYING PROPORTIONS OF RUBBER

It will be seen that recent research, particularly that carried out at Amsterdam, is helping to clarify the complex rheological behaviour of bituminous materials. Nevertheless, much remains to be done, particularly to determine the effects of binder content, of aggregate type and grading, of very high loads and pressures, and of repeated loading. It is also desirable to see how far polymer-modified bitumens can be characterized by the parameters now in use.

ADHESION

One of the major attributes of bitumen is the ease with which it can be made to adhere to all types of roadstone, and the high bond-strength achieved, provided the stone is dry and dust-free. Good initial "wetting" of the dry stone surface depends primarily on the viscosity of the bitumen, and with any given grade of bitumen there is a temperature below which "wetting" will be difficult or impossible. This fact decides: (1) the minimum temperature at which a premixed bituminous material can be prepared; (2) the maximum viscosity of surface-dressing binder which can be used by normal techniques under given climatic conditions. Accurate information on these points is not yet available, and more research is needed to enable, for example, reliable specifications to be drawn up for surface dressing with bitumen binder.

The bond-strength between stone and bitumen is high, and generally any failure in "adhesion" under dry conditions occurs by a rupture of the bitumen itself—a "cohesive" failure. It is known, however, that as the bitumen becomes harder, either by weathering or by lowering the temperature, the stone–bitumen bond weakens and may be ruptured. Even with a very fluid bitumen, however, a very rapid rate of loading can cause the bond to fail at the stone–bitumen interface.

The main problem of adhesion with bituminous surfacings occurs in the presence of water. The polar liquid water is strongly attracted to the surface of any roadstone containing silica, which carries a negative surface charge. These "orientation" forces between water and silica are much more powerful than the "dispersion" forces between the relatively non-polar bitumen and silica. The stone surface will thus possess hydrophilic properties, and in consequence a stone wetted with water cannot be properly coated with a normal bitumen; furthermore, a stone already coated with bitumen can be "stripped" by the action of water.

A great deal of work has been carried out, all over the world, to explain in terms of fundamental physico-chemical concepts the behaviour of stone–bitumen–water systems and to develop laboratory tests which would enable a prediction to be made of the likely behaviour of a given stone–bitumen combination on the road. So far the extreme complexity of the bitumen–stone system has defeated all attempts to describe its behaviour in the presence of water in more than very general terms. The large number of arbitrary laboratory tests which have been used to assess the relative performances of stone–binder combinations in the presence of water were discussed by Lee and Nicholas in 1952,[12] when it was emphasized that such tests have little or no value unless correlated with road behaviour, preferably with the results of properly controlled full-scale experiments. For the great majority of tests, no such evidence is available.

Surface Dressing

The relative preference of roadstone for water is of particular importance in surface dressing. The stone chippings are frequently wet when applied and cannot adhere to the bitumen until the water evaporates; this may take hours or even days in wet or humid weather, and failure of the dressing is then only too probable. Furthermore, even if good initial adhesion is obtained, subsequent wet weather before the dressing has "bedded down" may lead to displacement of

the binder from the surface of the chippings, and again failure may result.

A considerable amount of effort has been devoted to the solution of this problem, both at the Road Research Laboratory and at other research establishments, notably the Statens Väginstitut in Sweden, and a large measure of success has been achieved. Indeed, it can be claimed that, apart from one or two minor refinements of technique, a complete answer to the problem of wet-weather damage to surface dressings has been obtained. The key to the problem has been the use of surface-active agents of three main cationic types. These types are :

(1) long-chain aliphatic amines or polyamines containing about 15 carbon atoms;
(2) nitrogen ring compounds with long aliphatic chains attached to the ring; and
(3) quaternary ammonium compounds having at least one long aliphatic chain attached to the nitrogen atom.

These may be used in three different ways [13] :

(*a*) by dissolving them in the bitumen (relatively few agents can be used in this way, and concentrations of the order of 1–3 per cent are required);
(*b*) by dissolving them in a suitable volatile solvent and treating the surface of the chippings before use;
(*c*) by dissolving them in a suitable volatile solvent and treating the surface of the bitumen film before spreading the chippings.

The solvent used in methods (*b*) and (*c*) is usually a light creosote oil, but recent research suggests that water may be a suitable solvent with certain agents.

It has been observed that these adhesion agents are highly specific, and the precise amount to be used to give successful results at minimum cost varies with the type of stone, type of binder, atmospheric conditions, and traffic. It is therefore desirable to have a simple test which can give reliable information on this point. It has been found that the Immersion Tray Test [13] is a useful guide, and although it depends on a subjective assessment of coating, correlation with behaviour on the road is reasonably good, as shown in Table II.

Its extreme simplicity makes it particularly valuable for the practising engineer, who has to assess the efficacy and concentration of a given agent for the particular combination of binder and stone he intends using. At least one highway engineer uses a scale of figures based on this test in specifications for surface-dressing different classes of road : where traffic is heavy and fast a high standard is required in the test, and as the severity of traffic decreases, so the specification may be loosened. In this way a most economical use of the agent is achieved, consistent with a very low risk of damage by wet weather.

TABLE II

Correlation between the Results of the Immersion Tray Test and the Damage Sustained by Sections of Surface Dressing when Rain Fell During or After Work

Amount of agent used	Number of sites			
	Heavy rain or showers during or after work		Light rain or drizzle during or after work	
	No chippings lost	Chippings lost	No chippings lost	Chippings lost
Sufficient to give at least 90% coating on the Immersion Tray Test .	22	Nil	6	Nil
Sufficient to give 50–90% coating on the Immersion Tray Test . .	7	1	11	3

The Immersion Tray Test, having been shown to correlate reasonably well with road behaviour, has been used in the laboratory to solve the principal remaining problems connected with surface dressing under wet conditions. One of these, the work on which is not yet finished, is to determine what quantity of a given agent it is necessary to dissolve in different grades of binder under different temperature conditions to obtain a good result. It has been shown that the lower the temperature of test, the more agent is required with a given binder; alternatively, at a given temperature, the more agent is required, the harder the binder used. This effect is illustrated graphically in Fig 4, in which lines of constant efficiency are plotted for different concentrations of the same agent in binders of different viscosity at different temperatures. These results show quite definitely that the efficacy of the agent depends to a major degree on the viscosity of the binder at the temperature of test, which suggests that the rate of diffusion of the agent through the binder to the stone surface controls the extent to which the agent can act. This explains why, generally speaking, much more agent is needed when surface dressing is carried out in cold weather, and why the methods involving the application of the agent to the stone–binder interface require far less agent than that in which the agent is dissolved in the binder. This work will be published in detail when completed.

One of the principal difficulties connected with the use of adhesion agents dissolved in the bitumen is that no agent so far examined is both efficacious and stable to heat when in solution. In consequence, agents must be added to the hot binder shortly before being used; they are usually mixed in by circulating the binder through the spray-bar for some minutes. The

Immersion Tray Test is a useful method of checking whether mixing has been efficient: samples of the binder may be removed at intervals from the spray-bar and used in the test.[14]

As mentioned above, a recent innovation in the technique of using surface-active agents in surface dressing is the use of aqueous solutions. Special water-soluble cationic agents have to be used in this method; these are organic salts of the types of cationic agents referred to above. Laboratory tests indicate that they may be as efficacious as the agents

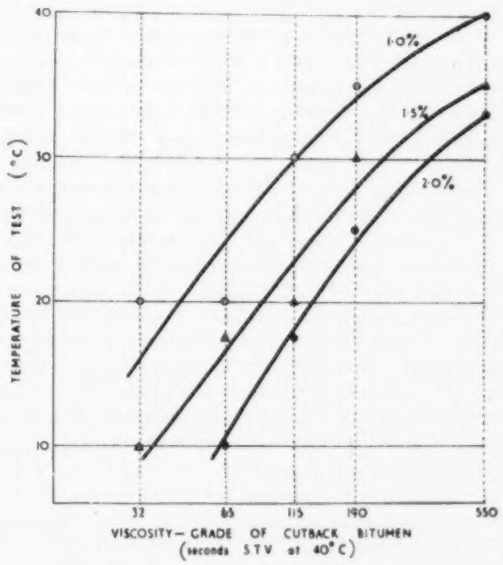

FIG 4

THE EFFECT OF TEMPERATURE AND VISCOSITY OF BITUMEN ON THE QUANTITY OF ADHESION AGENT REQUIRED TO GIVE SATISFACTORY RESULTS IN THE IMMERSION TRAY TEST

The curves connect points of satisfactory results with the given concentration of agent.

already in use.[15] Full-scale trials are planned for 1957 to confirm these laboratory results. The use of water as a solvent has several advantages, including those of cost, availability, cleanliness, and freedom from fluxing action. If these trials are successful, recommendations on these agents will be issued.

Asphalts and Coated Macadam

A properly-made rolled asphalt conforming with B.S. 594, adequately compacted when laid, is completely impervious to water, and stripping troubles cannot occur. With coated macadam and fine cold asphalt, however, the material as laid is pervious to water, and may remain so throughout its useful life. If the aggregate is an igneous rock or gritstone, the chances of the bitumen being stripped off it under heavy traffic is high, and such stripping is of frequent occurrence on all but lightly trafficked roads. Premature failure of such a surfacing is, however, infrequent. There is evidence to show that a stripped carpet will not fail unless the road structure as a whole has a pronounced flexibility and the carpet undergoes disintegration as a result of repeated heavy loading; an unstripped carpet is apparently able to cope with such movement without disintegrating. This suggestion is based mainly on observation, but some results of "stiffness" measurements on road structures lend it support.

While premature failure due to stripping is, as already mentioned, infrequent, stripping would be expected to play a part in deciding the ultimate durability of a carpet, and the relatively short life of 6 or 7 years now often obtained with bitumen carpets intended to comply with B.S. 1621 may be due, at least in part, to stripping of the binder from the fine aggregate, which then gets plucked out of the surface by traffic. The relative importance of this effect and variation or deficiency in binder content is not yet known.

Stripping in carpets and fine cold asphalt can be completely prevented by the use of one or two per cent of hydrated lime (or of a rather larger proportion of Portland cement) in the mixture, provided the bitumen has an adequate content of the right kind of acid. The outstanding problem still remaining in this process is the definition of the nature and quantity of acid required. It is known that some of the softer straight-run bitumens already contain sufficient acid for this process, but, generally speaking, addition of an acid is required. One of the simplest methods is to add either a tar or a tar-oil to the bitumen; with a straight-run bitumen, about 10 per cent of a vertical-retort tar of the appropriate viscosity is suitable; with a cutback, it is sufficient to ensure that at least one per cent of coal-tar phenols are present. As a preliminary step towards specifying the acid-content of bitumens for this hydrated-lime process, a new technique has been developed at the Road Research Laboratory for measuring both the strong and weak acids in bitumen by titration.[16] Apart from this question of specification of acid content, sufficient trials and experiments on the road have now been done to show that the lime process is quite reliable, and certain manufacturers and engineers have shown that it presents no technical difficulties.

It has been suggested that the addition of 10 per cent of tar without the use of hydrated lime or cement is sufficient to prevent stripping, but full-scale experiments and observation of commercially-laid carpets indicate that, while there is some reduction in the severity of stripping, complete prevention is not obtained.

Another method of preventing stripping in carpets or fine cold asphalt is to incorporate in the mixture a small proportion of a surface-active agent, such as

those already mentioned in the case of surface dressing. So far the Laboratory has shown, in a full-scale road experiment, that complete prevention of stripping can be obtained, in the case of one stone, with such agents, but the amount necessary varies with the agent. It is also probable that different stones will require different amounts of agent, and so a further full-scale experiment is being carried out with a number of stones and a range of concentrations of four agents to obtain information on this point. The results of this experiment will be related directly to the results of laboratory tests on mixtures similar to those laid on the road, and it is hoped to gain further evidence of correlation between road performance and the Immersion Wheel-Tracking Test. This test, which has been described elsewhere,[12, 17] has already given evidence of correlation with practice, but a more detailed picture is needed from a single full-scale experiment. The test is at present being examined for repeatability and reproducibility by several laboratories in collaboration with the Road Research Laboratory.

Stripping also appears to be a common phenomenon in macadam base-courses under pervious carpets, but it is not known to what extent this is due to the same factors as in the wearing course, where traffic plays a major role in the stripping process. A stripped base course may become unstable and lead to failure of the wearing course, particularly if the base course is thick in relation to the maximum size of stone it contains.

DURABILITY

The durability of a bituminous road surfacing is determined mainly by the degree of resistance of the binding medium to atmospheric weathering. An open-textured carpet exposes the bitumen to the atmosphere throughout the whole body of the carpet; in a well-compacted rolled asphalt with a voids content of less than 5 per cent, the bitumen in the body of the asphalt is sealed from atmospheric influences, and only the bitumen in the surface is exposed. In a fine cold asphalt there is an initial condition when the atmosphere can reach the bitumen throughout the surfacing, but traffic gradually causes the material to pack closely together, and eventually the bitumen in the interior of the carpet becomes sealed off from the atmosphere.

These different conditions of exposure largely account for the differences found between the average lives of such surfacings. The records kept by a number of highway engineers throughout the country have shown that the average life of an open-textured bitumen carpet is 5 to 6 years and that of a fine cold asphalt is 9 to 10 years, whereas that for rolled asphalt is over 20 years. The life of a surfacing is the time from when it is laid to when it receives its first maintenance treatment: the individuals within one type vary greatly in their lives, but these figures are the arithmetic averages of a large number of each type. Of the many factors that can cause large variations in the life of a particular type of surfacing one of the most important is variation in the bitumen content. In a dense material of the rolled asphalt type, any excess binder above the optimum for the particular traffic intensity will appear on the surface and give a dangerously slippery road. A deficiency of binder will cause the material to be permeable to air and water, and premature failure will occur by disintegration as a result of weathering of the bitumen or by stripping of the bitumen from the aggregate by water. A surface that is permeable when first laid, such as coated macadam or fine cold asphalt, closes up under heavy traffic and, on heavily trafficked roads, variations in bitumen content will again cause slipperiness and deformation on the one hand, and premature disintegration on the other.

Thus the key to long life, with freedom from slipperiness due to excess bitumen, is the selection of the optimum bitumen content. A large number of experimental open-textured bitumen carpets have been laid for the purpose of studying this factor; it has been found that whereas a bitumen content of, say, 4 per cent will give a life of 8 years or more on a main road, a change by 0·5 in the binder percentage will reduce the length of life to less than half. Some examples are given in Table III of carpets made with certain types of aggregate in common use.

TABLE III

Road Experiments on Bitumen Macadam Carpets—Effect of Variations in Bitumen Content on the Life of Carpet

Site	Aggregate	Fines content (passing ¼ inch)	Bitumen content	Life (years)
Bath–Bristol Road (1945)	Dolerite	20	4·0	>8
		20	4·5	4 *
		10	4·0	>8
		10	4·5	3 *
Gt North Road (Huntingdon) (1946)	Dolerite	20	4·0	>8
		20	4·5	3 *
		20	3·5	4 †
Stafford–Cannock Road (A34) (1948)	Quartzite	20	4·0	>7
		20	3·5	4 †

* Slippery. † Disintegrates.

On lightly trafficked roads open-textured carpets close up to a much smaller extent, and the tolerance on binder content becomes much wider before disintegration or smoothness becomes apparent.

Thus on heavily trafficked roads with certain aggregates there is a very small tolerance in the limits of bitumen content, leading to disintegration, on the one hand, and slipperiness, on the other. Results of

experiments involving other bituminous binders have shown that this tolerance becomes smaller as the susceptibility to weather action becomes greater: in the extreme case of a binder that suffers rapid attack by exposure to weather, no binder content in an open-textured carpet would give a satisfactory life of more than 2 or 3 years on a heavily trafficked road. One would expect that a bitumen that showed a good resistance to weather action in the U.K. would show less resistance in tropical climates, and so would show a smaller tolerance in the bitumen content for satisfactory open-textured carpets in such areas.

It will be seen therefore that the intrinsic durability of the bitumen itself is of great importance to the highway engineer. With a binder having a high resistance to weathering, low binder contents can be tolerated to a much greater extent in coated macadam surfacings than with a binder of poor resistance to weathering. On the other hand, in the case of dense asphalt surfacings, a bitumen with a high resistance to weathering can give a less satisfactory material than one that is less resistant; the reason for this is that as the material becomes highly compacted by traffic the bitumen that migrates towards the surface will be more easily worn away by traffic if it hardens by weather action, and so a skid-resistant surface finish will be more easily maintained; bitumen that is more resistant to weathering will tend to remain in the surface of the road and produce a smoother and less skid-resistant surface.

In the U.S.A., where a large and rather bewildering variety of bitumens is available, the problem of assessing the durability of bitumen has always been a major one, and much research has been devoted to it. No conclusive results have yet been forthcoming, however, although several authors have pointed out the importance of the resistance of the bitumen to oxidation.[18, 19] One recent suggestion is that the flash-point of the bitumen is related to its behaviour in practice;[20] it seems unlikely that this is true on the road, although hardening during mixing may well be related to evaporation at high temperatures, and hence to the flash-point. Research on the durability of tarmacadam and tar-carpets has shown that the hardening of coal-tar binders in this type of surfacing is due almost entirely to atmospheric oxidation; very little can be accounted for by evaporation of volatile constituents.[21] Straight-run bitumens are practically non-volatile at road temperatures, so that the predominating factor in weathering would be expected to be oxidation.

In the U.K. the problem of the durability of bitumen has never been so acute as in the U.S.A., for several reasons. The rolled asphalts in the U.K. are generally richer mixtures than their counterparts in America, and if properly made and laid they have a life of 20 years and more even on the most heavily trafficked roads: the main problem with them is the provision of a non-skid surface, for which a moderate degree of weathering of the binder is desirable. All the bitumens that have been generally available here have had a reasonable or high resistance to weathering. The relative performance of certain straight-run bitumens from various sources was shown by the road experiment begun on the Colnbrook By-pass in 1937, in which two series of asphalts were laid using different bitumens as binders: one series consisted of 2-inch surfacings of rolled asphalt, complying with B.S. 594, with a 50 per cent stone content, the other series consisted of 1½-inch thick bitumen-macadam surfacings containing 25 per cent of fine aggregate passing ⅛ inch. The aggregate grading and soluble bitumen content were the same for each section of a series; Trinidad Lake asphalt épuré was fluxed with a non-volatile petroleum flux oil to give an asphaltic cement having a penetration of 65, and an allowance was made in the aggregate grading for the mineral content of this asphaltic cement, so that the grading of the complete aggregate of the final asphalt was the same as for the asphalts made with the residual petroleum bitumens. Samples were cut from the surfacings after various periods of time; analyses were made of the compositions, and the bitumens were recovered by the method using carbon disulphide, as described in B.S. 598. The penetration values for the recovered bitumens are given in Tables IV and V.

TABLE IV

The Penetrations of Different Types of Bitumen Recovered from Bitumen Macadam Carpets after Various Intervals of Time on A4 (30,000 tons of Traffic/Day)

Type of bitumen	Pen of A.C. in binder heater	Penetration of bitumen				
		Recovered from sample from binder heater	Recovered from road before traffic	Recovered from road after		
				2 years	10 years	14½ years
Venezuelan	52	—	46	40	27	22
Mexican	58	—	50	42	17	24
Californian	56	—	58	53	—	43
Trinidad Lake asphalt	65	195	138	67	30	30

TABLE V

The Penetrations of Different Types of Bitumen Recovered from Rolled Asphalts after Various Intervals of Time on A4 (30,000 tons of Traffic/Day)

Type of bitumen	Pen of A.C. in binder heater	Penetration of bitumen						
		Recovered from sample from binder heater	Recovered from road before traffic	Recovered from road after				
				2 years	10 years	12 years	14½ years	17 years
Venezuelan	60	—	47	50	60	65	58	50
Mexican	57	—	50	49	47	—	46	41
Californian	59	—	58	56	—	—	60	52
Trinidad Lake asphalt	65	192	145	105	93	76	62	50

It will be seen that in the open-textured carpets the penetrations of the Venezuelan and Mexican bitumens had been reduced to about half of their original values after about 15 years; that of the Californian bitumen had been reduced to about three-quarters of the original value; the Trinidad bitumen had hardened to a penetration between a quarter and a fifth of the original value.

The carpets made with the Venezuelan, Mexican, and Californian bitumens were all in fairly good condition 18 or 19 years after laying when the road was widened and partly reconstructed in 1956. The carpet made with the Trinidad Lake asphalt, however, was not as durable; it showed some disintegration after about 10 years, and it had badly failed after 14 years. The difference in road performance between the Trinidad bitumen and the other bitumens does not correspond to the figures for the penetration of the recovered bitumen after 14½ years on the road; either there is some critical distribution of hardness throughout the binder that is not revealed by the bulk recovery, or some factor other than hardening of the bitumen must have operated. It has been suggested that a factor determining the durability of these carpets is the stiffness of the bitumen–filler mixture which acts as the binding medium between the coarse aggregate. If the stiffness of this medium becomes high, a brittle condition will be reached which would cause disintegration under traffic forces. Evidence has been obtained which shows that the natural mineral filler in the Trinidad asphalt has a greater stiffening action than the limestone filler used in the manufacture of the carpets, but there is no evidence to show that this effect is large enough to account for the difference in performance.

It will be seen that similar relative changes in hardness of the bitumens occurred in the dense rolled asphalts, although these surfacings were all in good condition after 17 years, and no failures had occurred. The sections, however, showed very significant differences in surface texture and in their resistance to skidding when wet. The surfaces of the sections made with Venezuelan, Mexican, and Californian bitumens were smooth and had a characteristic "veined" appearance, in which areas of "pure" bitumen seemed to be breaking through the mortar in the surface. The sections containing Trinidad Lake asphalt, on the other hand, had a pronounced "sandpaper" finish. Figs 5 and 6 illustrate these textures.

It would appear that this difference in surface texture is related to the different rates of hardening of the bitumens. The figures quoted are for the whole of the bitumen in the rolled asphalt; if the assumption is made that atmospheric oxidation is the prime cause, then considerably greater hardening would be expected in the surface layers than in the body of the rolled asphalt. Thus, although the average value for penetration was the same for all the asphalts, the surface hardening would be expected to be much greater in the case of the Trinidad asphalt. A technique has been developed for measuring the viscosity of the bitumen in the top layers of the mortar

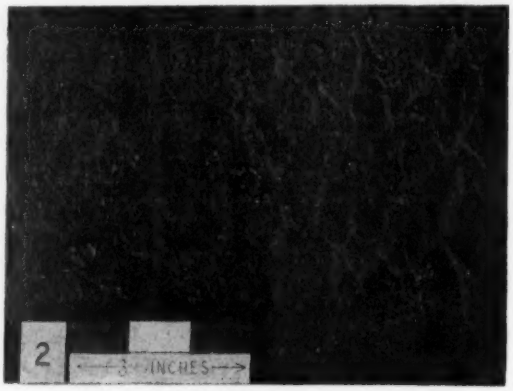

FIG 5

CLOSE-UP PHOTOGRAPH OF THE SURFACE OF A ROLLED ASPHALT, CONTAINING VENEZUELAN BITUMEN, AFTER 18 YEARS ON THE COLNBROOK BY-PASS (TRUNK ROAD A4)

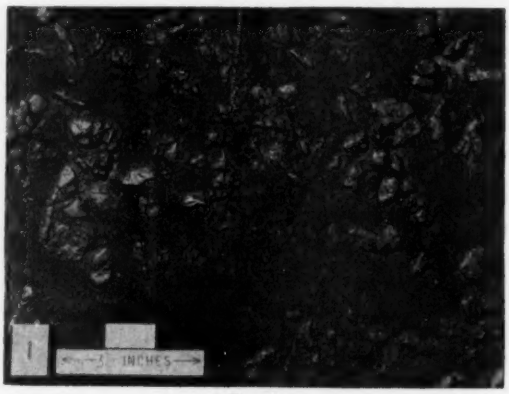

FIG 6

CLOSE-UP PHOTOGRAPH OF THE SURFACE OF A ROLLED ASPHALT CONTAINING TRINIDAD LAKE ASPHALT, FLUXED WITH OIL, AFTER 18 YEARS ON THE COLNBROOK BY-PASS (TRUNK ROAD A4)

in the road surface. The top surface of the asphalt mortar is scraped away in three successive layers, each about 20 thousandths of an inch in thickness; the bitumen in the material removed in each layer is dissolved out in carbon disulphide, and the viscosity of the recovered bitumen is measured in a micro-viscometer. These measurements have shown that the bitumen on the surface of the asphalts made with Trinidad bitumen has a viscosity over a hundred times that in the body of the surfacing, *i.e.* a viscosity of the order of 10^8 poises. In the case of the asphalts

made with Venezuelan bitumen, however, the surface bitumen has a viscosity of nearly a hundred times less than that in the interior, *i.e.* about 10^4 poises, except for the edge of the carriageway where traffic does not behave on the road similarly to the Trinidad bitumen. It was found that such a change can be made in the oxidation characteristics of Venezuelan bitumen by dispersing in it various proportions of certain coal-

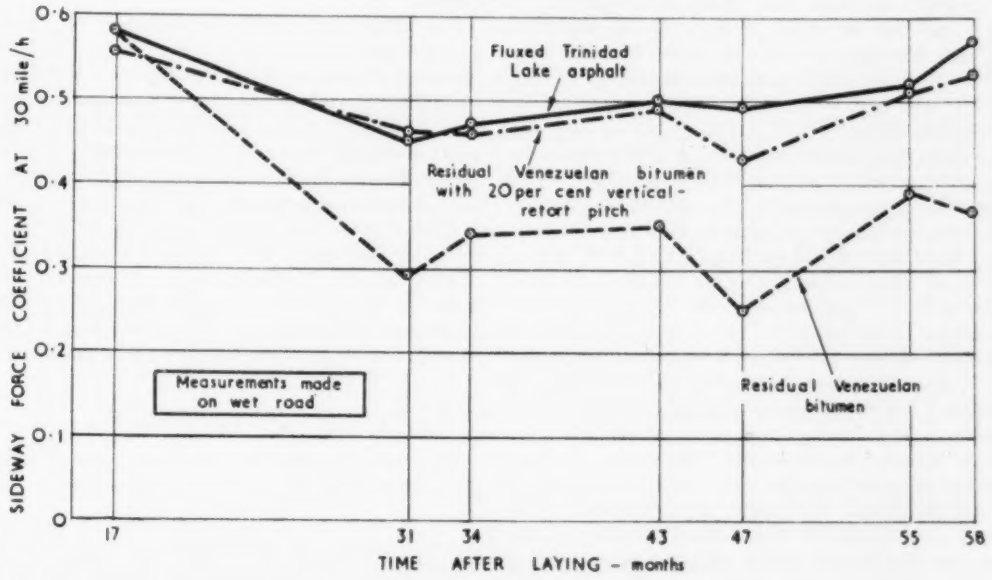

FIG 7

THE RESULTS OF SIDEWAY FORCE COEFFICIENT MEASUREMENTS ON ROLLED ASPHALTS CONTAINING DIFFERENT BINDERS
Binder content in each case—7·7%

travel, where the surface bitumen has a viscosity about ten times greater. The simplest explanation of this softening effect is the contamination of the asphalt by oil dropped from passing vehicles.

It would appear that in spite of the softening effect of the oil, the surface of the Trinidad asphalt hardens considerably so as to permit a certain amount of abrasion by traffic. Evidence to support the theory that a difference in resistance to atmospheric oxidation is the basic reason for the difference in road performance is given by laboratory oxidation tests. A laboratory test that has given useful results for measuring the oxidation of road tar,[21] has been applied to these bitumens. The bitumen is subjected to oxygen at a pressure of 20 atmospheres at 65° C for a period of 200 hours. The change in the hardness of the bitumen is determined by measuring the Fraass Brittle temperature before and after the oxidation. The increase in Fraass Brittle temperature was 2·5° C for the Venezuelan bitumen and 9° C for the Trinidad bitumen.

It was thought that if the oxidation resistance of the Venezuelan bitumen could be brought down to that of the Trinidad, then, if oxidation was the important factor, this modified Venezuelan bitumen should tar pitches that are particularly susceptible to oxidation, such as vertical-retort pitch and low-temperature-carbonization pitch. The results obtained with various mixtures are given in Table VI; it will be

TABLE VI

Results of Pressure Oxidation Test on Venezuelan Bitumen Containing Highly Oxidizable Coal-tar Pitches

(All mixtures adjusted to have a penetration of 60–70)

Binder	Rise in Fraass Brittle temperature after oxidation (200 hours at a pressure of 20 atmospheres at 65° C), ° C
Venezuelan bitumen	2·5
Venezuelan bitumen + 2% low-temp carbonization pitch	7
Venezuelan bitumen + 5% low-temp carbonization pitch	8
Venezuelan bitumen + 10% low-temp carbonization pitch	10
Venezuelan bitumen + 10% vertical-retort pitch	5
Venezuelan bitumen + 20% vertical-retort pitch	5·5
Bitumen extracted from fluxed Trinidad Lake asphalt	9

seen that by such mixtures it is possible to increase the rate of hardening of the Venezuelan bitumen as measured by the Fraass test to that of the Trinidad asphalt.

A full-scale road experiment was accordingly carried out in 1951 on Trunk Road A40 (at Greenford), in which sections of rolled asphalt complying with B.S. 594, having a 50 per cent stone content, were laid with these seven materials as binder: each asphalt was laid with three binder contents, the percentages being 5·8, 6·8, and 7·7, so as to cover the range from the bottom to the top of the limits for Schedules 1 and 2 of the British Standard. The sections have now carried traffic (25,000 tons/day on each carriageway) for just over 5 years, and measurements have been made during this period of the resistance to skidding. The results for the three asphalts made with 7·7 per cent of the Venezuelan, the Venezuelan containing 20 per cent vertical-retort coal-tar pitch, and the Trinidad asphalt are shown in Fig 7. It will be seen that the modified Venezuelan bitumen is behaving similarly to the Trinidad Lake asphalt.

It is noteworthy that the differences in skid-resistance between asphalts with Venezuelan bitumen, on the one hand, and those with Trinidad Lake asphalt or the modified Venezuelan bitumen, on the other, are of the order of 0·2 S.F.C., despite the fact that the asphalts contain 50 per cent of stone and a light application of coated chippings. This suggests that the effect of the weathering of the binder on the skid-resistance of the mortar is very marked; it is able to show its influence even when more than half the surface consists of stone.

FUTURE RESEARCH

Under the conditions prevailing in the U.K., deformation of bituminous road surfacings is not a serious problem, except at busy bus stops and similar sites of exceptional stresses, where special materials can be laid which would not be economical for the whole road surfacing. On the other hand, the very high loads and pressures now being applied to airfield runways and taxiways make the problem of deformation of particular importance in these circumstances. Cracking is a relatively minor problem in this country, except in asphalt over concrete joints. Except, therefore, for special applications, major improvements in the rheological properties of bitumen are not urgently required. However, as the ultimate failure of bituminous surfacings is frequently associated with disintegration, it may be that improved brittle properties would lead to a longer life in many instances.

In the field of adhesion, many of the more important problems are well on the way to a practical solution, although the fundamental background for this work is still only sketchily filled in. One of the outstanding questions still to be answered is whether the complete prevention of "stripping" by water significantly improves the overall durability of bitumen macadam carpets.

The durability of bitumen surfacings is a field in which much remains to be done. Even though the bitumens at present available here are of satisfactory durability, there is no guarantee that at some future date an entirely new source of bitumen may not be used to supply the needs of this country, and it is essential to be prepared for such a contingency by having available adequate durability tests to assess the likely behaviour of such a bitumen in the various forms of road surfacing. An understanding of the mechanism of the hardening of bitumen in road materials is therefore of primary importance. Such knowledge is necessary for the selection of bitumens most suited for providing durable non-skid surfacings.

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HOT ASPHALT CONSTRUCTION *

By P. C. LEAVER †

SUMMARY

In this paper hot asphalt construction has been selected as an example of the use of bitumen in road work, as it offers considerable scope for examination and discussion. A life of 20 years is not uncommon for hot asphalt. The compositions and applications of contemporary materials, such as bitumen macadam, fine cold and mastic asphalts are, however, briefly discussed. Comparisons of costs and normal contract maintenance periods between the materials are made.

The scope of hot asphalt in terms of materials and types of construction, such as roads and airfields, is demonstrated. The selection, for a given set of conditions, of a mixture from the British Standard stems largely from the experience of the engineer and contractor. The question is raised as to the value of this approach in the light of rapidly changing traffic conditions. Practical problems associated with manufacturing and laying are given in detail. It is emphasized that in manufacturing plant the prime need is for a greater degree of automatic control. On the laying side, more effective aids are required to provide an accurate running surface whilst the material is being spread.

Details and problems of a large-scale contract are described. Leading from this it is explained that most contract conditions require sampling and testing to be carried out in accordance with the British Standard. The methods available in the existing Standard are completely inadequate for modern conditions, although a new edition will soon be issued containing other methods. Furthermore, the value of analyses as understood in this connexion is questioned in relation to the information it provides the engineer. Finally, several examples of asphalt construction are reported with the object of showing the different circumstances in which the material can be used.

INTRODUCTION

THE use of bitumen, mixed with other materials, can take many forms in road construction. In the U.K., British Standard Specifications are available to cover a wide range of differing circumstances of traffic loading and climatic conditions. Bitumen grades from low penetration types for heavy duty purposes to fluid cutbacks, where flexibility may be a consideration, are easily available. Briefly, the bituminous road materials used are as follows:

(1) *Bitumen Macadam* [1, 2]

As this material has a preponderance of stone, it is usually manufactured at, or close to, a quarry. All natural rocks, slag, and gravels may be used. With the two former aggregates the binder may be of soft bitumen (150–500 pen) or cutback bitumen (30 sec at 30° C to 500 sec at 40° C); with gravel, the binder may be bitumen of 180–320 penetration or a blend of bitumen and lake asphalt of 100–130 penetration. Manufacturing temperatures are within the range of 150°–250° F. Bitumen macadams may be used to shape and level existing roads or to provide new construction. Their flexible nature is of great advantage under the last heading. Thicknesses of such shaping courses could be from 2 to 3½ inches. Top course macadams are widely used to provide new running surfaces of about 1 inch. Sites such as trunk and main roads, housing estates, and some city streets are instances where these materials may be used. By choosing a bitumen of suitable viscosity macadam may be transported over long distances.

(2) *Fine Cold Asphalt* [3]

Fine cold asphalt consists essentially of a fine graded crushed rock or slag and either a soft or a cutback bitumen (pen 180 min). It derives its strength through mechanical interlocking as the result of a controlled grading. When spread upon the road and compacted, it soon develops into a hard surface. Being finely graded, it is used only as a surfacing course in thickness of ½–1 inch. The texture of the material may be modified by the inclusion of ⅜–¼-inch aggregate, together with the application of pre-coated chippings. One of the main advantages of cold asphalt is that it can be mixed and stored for some time after manufacture and laid in the cold state to give excellent results. It is a versatile material which can be used on such different sites as footpaths and city streets. It is particularly useful for providing a surface in a thin layer to existing roads, where, if other bituminous surfacing were applied, extensive kerb raising would be necessary.

(3) *Mastic Asphalt* [4]

Mastic asphalt for roads and footpaths provides a surface of extremely long life. It consists of fine limestone dust mixed with either lake asphalt or refinery bitumens of hard penetrations (20–40 pen). It is used as a surfacing material under conditions where very heavy loads may be expected. Bus

* MS received 26 February 1957.

† George Wimpey & Co. Ltd.

stops, parking bays, and steel-wheeled traffic are examples. The manufacture of mastic asphalt is a slow process carried out in a special plant. Spreading is by hand at temperatures of 400° F. There are some machines of Continental design which can lay mastic asphalts mechanically. Thicknesses vary from 1 to 2 inches. In the upper limits of thickness, however, the addition of coarse aggregate is necessary to give additional stability. Pre-coated chippings are usually added to the surface of the material whilst warm.

(4) *Hot Asphalt*

Hot asphalt, in common with bitumen macadam, may be used to construct and surface a road, as distinct from cold and mastic asphalts, which are used in thin layers. It differs from bitumen macadam, however, in respect of its much higher shear strength. Working temperatures are from 300° to 350° F. Hot asphalt is a heavy-duty material which, due to modern plant and equipment, can provide large areas of high-quality construction very rapidly.

Of the foregoing bituminous road materials, mastic and hot asphalt have the longest life. Materials of this type laid over 20 years ago are still giving satisfactory service. It is usual to give contract maintenance periods of 5 years for hot asphalt, 3–5 years for mastic asphalt, and 1–3 years for bitumen macadam and fine cold asphalt. As far as cost is concerned, this will depend on a multitude of factors, such as availability of materials, haulage, thickness, specification, and type of contract. Approximately, at a thickness of 1 inch, the ratio would be as follows:

Bitumen macadam	1·00
Fine cold asphalt	1·33
Hot asphalt	1·40
Mastic asphalt	3·57

From this brief review it is felt that hot asphalt offers the most interesting example of bituminous road construction because it can be used in a variety of ways, from providing a surface to an existing road to constructing a new pavement capable of supporting traffic loading of all types from light vehicles to heavy aircraft.

THE SCOPE OF HOT ASPHALT IN MATERIALS AND CONSTRUCTION

It might be as well to point out that, so far as this paper is concerned, the term "hot asphalt" is meant to convey the following:

> A carefully-proportioned mixture of coarse and fine aggregates (stone, sand, and filler) combined at an elevated temperature with a bituminous material spread and compacted whilst warm to provide part of a traffic-bearing structure.

Furthermore, as the bituminous part of such a mixture is popularly subject to a variation of terminologies (namely, bitumen, binder, asphalt, matrix) the expression "asphaltic cement" has been taken as the most effective in describing the function of the bituminous material. At the same time, it must be stressed that the "soluble" bitumen content of the "asphaltic cement" is the real basis of asphalt specifications.

A large number of balanced combinations with different physical characteristics can be obtained with the prime ingredients of an asphalt mixture. An examination of the available specifications will serve to illustrate this point. Hot asphalt is covered by:

(1) The British Standard Specification.[5]
(2) The Air Ministry Specifications.[6, 7]

(1) *The British Standard*

(a) *Development and Scope*

The first British Standards for hot asphalt were published in 1928, although the material had been in use for many years previously. Subsequent revisions have always tended to increase the range of mixtures by placing at the disposal of the engineer a wider choice of materials capable of being combined in a greater number of ways. Most particularly, it must be pointed out that the guiding rule has been that of established good performance. In other words, a wide survey has been necessary to determine the various combinations of basic materials which are known to provide a sound mixture.

The Standard is divided into four parts. The first two cover single- and two-course construction with igneous, calcareous, or siliceous rocks, whilst the remaining two parts deal with gravel aggregates in either one or two courses. Asphaltic cements cover refinery bitumen, fluxed lake asphalt, and blends of equal proportions of bitumen and lake asphalt. These materials are specified to give penetration ranges of 30–40, 40–60, and 60–80. Thicknesses are 1–1½ inches for wearing courses laid on a base course and 1½–3 inches when applied in a single layer. Base courses may be laid from 1½ to 3 inches, although multi-layers (some cases can be quoted of total depths of 2 ft) are permitted, provided that each layer does not exceed 3 inches in depth.

(b) *Choice of Specification*

From the foregoing brief review of the Standard's scope it might be as well to examine the range of each part in relationship to the choice of specification or mixture. Each part offers the following:

Part 1. 24 mixes with 6 types of asphaltic cement.
Part 2. 12 wearing-course mixes with 9 types of asphaltic cement.

5 base-course mixes with 6 types of asphaltic cement.

Part 3. 15 mixes with 6 types of asphaltic cement.

Part 4. 9 wearing-course mixes with 6 types of asphaltic cement.

3 base-course mixes with 6 types of asphaltic cement.

In circumstances where considerable thicknesses of paving are required, an asphalt mixture from the single-course sections may be imposed on a base coat taken from the relative two-course part of the Specification. Therefore, when the number of mixes is multiplied by the various penetration grades and types of asphaltic cements, and account is taken of the incremental variations in thickness throughout the specified ranges, together with interrelationship between the various parts of the Specification, the number of possible choices available to the engineer becomes considerable.

On the one hand, it may be claimed that the Specification places at the engineer's disposal means whereby any constructional scheme may be covered. The alternative view is that the engineer is seeking to obtain from this formidable assembly of possibilities an asphalt mixture or mixtures suitable for his particular requirements. A useful Appendix to the Standard deals generally with the selection of mixes in the light of traffic conditions and weather and, therefore, assists in limiting the range of choice. It is pointed out, however, that the choice of an asphalt mixture depends significantly upon the skill and knowledge of the engineer and contractor. It is undeniable that this experience has served the purpose extremely well. The question might be canvassed, however, as to the value of this experience in view of the steeply rising rate of vehicles coming on to the roads, heavier loads, possibly a new road system, and perhaps new forms of propulsion, with consequently higher speeds.

In short, therefore, in the absence of other means of design, advantage must be taken of experience. Some of the points which will influence selection within the scope of the Specification are as follows:

(i) *The Condition of the Existing Road.* The minimum thickness of a single-course asphalt wearing course is 1½ inches laid in a single coat. If a road has become so deformed as to render it difficult to maintain this depth over all the road, reshaping is necessary either by burning off or by the use of a base course. The position of kerbs and the amount of upstand will have some bearing on this choice. Attention must be paid to the relationship in level of the site under consideration to the surrounding roads. Foundations have to be examined and all weak spots stabilized. If new construction is envisaged two-coat work is desirable.

(ii) *The Expected Traffic Loading.* Where heavy-duty conditions apply, an asphalt mixture having a high degree of stability must be selected. Stability is governed by the stone content and the grade of asphaltic cement. Therefore a medium-high stone content with one of the harder grades of asphaltic cement should be specified. Furthermore, the thickness of pavement will have to be such that it is sufficient to disperse or shield the load from the subgrade. In some cases, such as bus stops and traffic lights, which experience fairly heavy shock impacts, it might be necessary to pave the area concerned with a special mixture. Lighter traffic conditions will require a different assessment. As the tyre effect will be less, a more closely-knit surface with a higher bitumen content is desirable. Trunk roads and minor city streets fall within this category.

(iii) *Weather Conditions.* Where cold, wet conditions prevail it is desirable to choose a mixture which has a dense, impervious surface (namely, mixtures with a stone content at the lower end of the range) together with a soluble bitumen content in the higher schedules. The harder grades of asphaltic cement are not advisable in these circumstances. In the case where milder weather is encountered, the choice would be medium stone contents with the harder grades of asphaltic cement, based on a mixture from the "leaner" schedules.

(iv) *Economics.* Assuming a mixture has been selected which takes into account the foregoing factors, some attention must be paid to cost. For example, in the case of aggregates, note has to be taken of any locally-occurring materials, such as gravel in East Anglia and granite in Leicestershire. The current relationship in price between lake asphalt and refinery bitumen has to be considered. On the organization side consideration must be given to letting the contract in sufficient area to warrant the importation of plant. In addition, the contract should provide continuity of work. Where possible, winter working is to be avoided, as this means lower outputs which will be reflected in the cost.

(2) *Air Ministry Specifications*

It is felt that brief remarks on the developments, scope, and choice of specifications for airfields will be of assistance in covering the function of this paper.

(a) *Development and Scope*

When asphalt surfaces for airfields are considered, it is necessary to bear in mind the great difference in traffic loading as opposed to roads. Leaving aside new construction, asphalt work on roads is usually concerned with a carriageway which is made up of several layers of old paving, well compacted by the constant passage of traffic. Although a runway may equally be constructed in layers, it is unlikely to have received a similar degree of traffic. Furthermore, although a road will receive a large volume of com-

paratively light traffic, a runway will have to withstand much greater gross weights, accompanied by high tyre pressures. It seems clear, therefore, that when discussing asphalt for use on airfields it must be considered as part of the pattern of the overall design from the subsoil upwards.

Asphalt surfaces for airfields developed substantially as a result of wartime requirements. The first specifications centred on a tarmacadam base course with a ¾-inch-thick asphalt wearing course. As loading increased, asphalt surfaces of a higher stability were required. Hot asphalt is used for both base and wearing courses only in pavings where high loading and high tyre pressures will be involved. The choice of mixtures is more limited as compared with the British Standard. Single- and two-course construction are specified, both mixtures having high stone contents. The specification [6] for the coarse and fine aggregates involves a different form of gradation from that in the British Standard, but the latest revision now conforms to the B.S. Asphalt cements are refinery bitumens of either 60–70 pen (for perimeter tracks) or 90–110 pen (for runways). Thicknesses range from 2 to 3½ inches for base course and ¾ to 1½ inches for wearing course. In some circumstances base coat may be laid in layers similar to the British Standard.

(b) *Choice of Specification*

Briefly, the use of asphalt on runways falls into the following categories:

(i) Resurfacing designed to provide a new and better shape of existing work. This may take the form of a single- or two-coat application.

(ii) Part of a strengthening job in which either rolled dry lean or pavement quality concrete is involved. Total pavement thickness, including the concrete, may be up to 2 ft, not taking into account the existing runway. Two-coat asphalt is normally used in these circumstances.

(iii) Extensions or diversions on existing airfields requiring construction from the subgrade upwards. Two-coat work may be specified in some circumstances.

ASPHALT MANUFACTURING PLANT

When considering asphalt manufacturing plant it is as well to define what is expected from such equipment. An asphalt plant is required to:

(1) Heat the materials to the required temperature.

(2) Measure them in the specified amounts.

(3) Mix them mechanically into a uniform mixture.

An important difference between a hot asphalt plant and other bituminous production lies in the temperature element. Where temperatures are lower, and bitumens of a more fluid nature are used, *i.e.* macadam, the mixed material can be hauled for longer distances. The nature of hot asphalt imposes limits on transportation; therefore the plant has to be as near the contract as possible.

FIG 1

THE PARKER "STARMIX" PLANT, ILLUSTRATING PORTABILITY AND METHOD OF ERECTION

Consequently, great importance is placed on portability and mobility in asphalt plant design. Haulage and erection of a plant may cost, depending on distance, £800–£1000. Contracts of a magnitude able to express this amount as a very low figure/yard can therefore be economically encompassed. Attention is focused on plant layouts which can be broken down into the minimum number of parts and are capable of being put into operation within a short time of being hauled on the site. Examples of trends in this direction are given in Figs 1, 2, and 3.

Asphalt plant outputs range from 10 to 100 tons/hour. The use of the smaller units is of doubtful value, both as regards quality and economy. First, smaller batches can lead to greater variations, together with temperature losses whilst loading. Secondly, as it usually takes the same number of men to operate either a high- or low-output plant, the cost

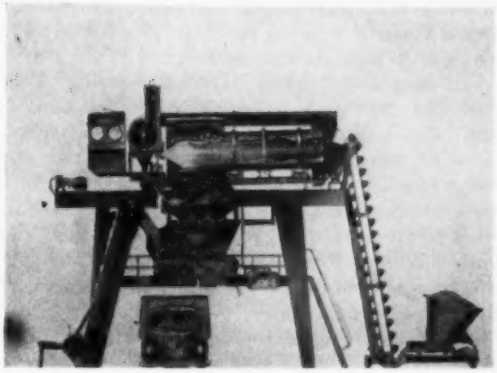


FIG 2

THE PARKER NO. 38 ASPHALT PLANT WHICH IS COMPLETELY PORTABLE AS A SINGLE UNIT

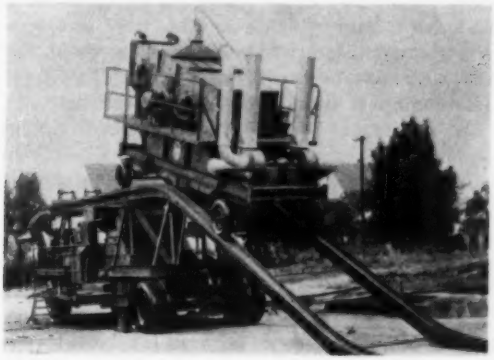


FIG 3

THE GERMAN "WIBAU" ASPHALT PLANT, DEMONSTRATING A FURTHER EXAMPLE OF PORTABILITY AND EASE OF ERECTION

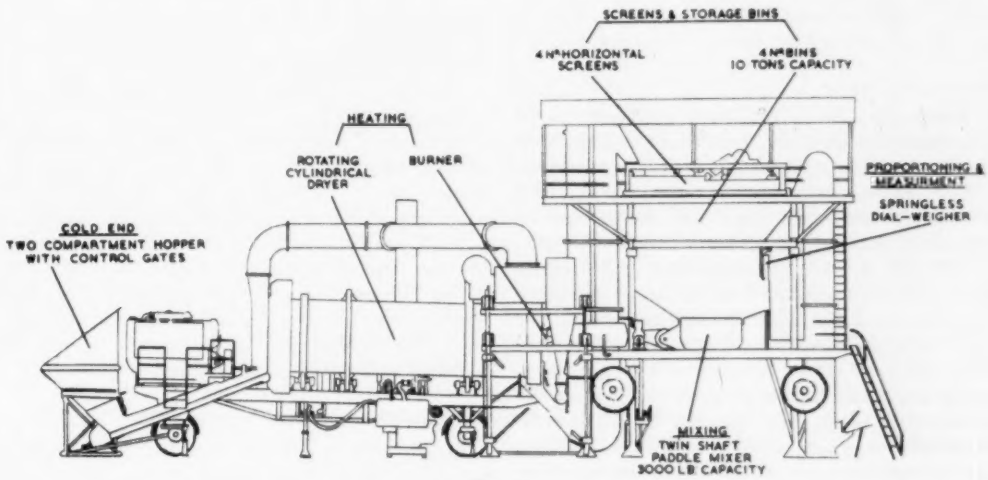


FIG 4

LAYOUT OF THE PARKER "STARMIX" ASPHALT PLANT OPERATING ON THE BATCH METHOD OF MIXING

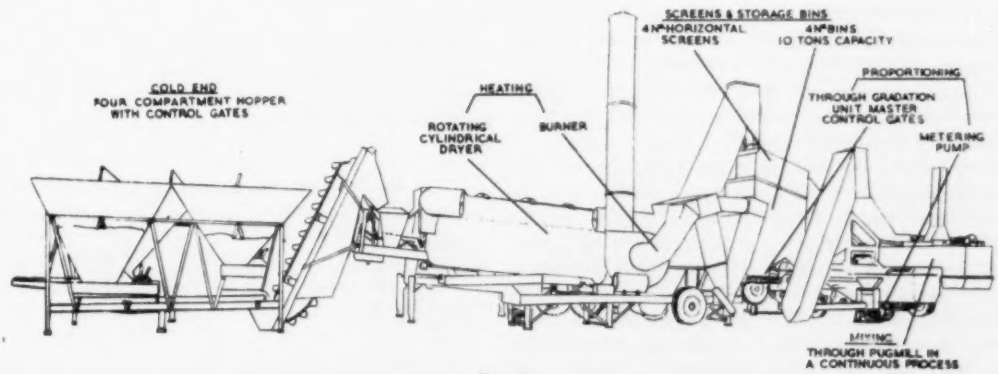


FIG 5

LAYOUT OF THE BARBER–GREENE ASPHALT PLANT OPERATING ON THE CONTINUOUS METHOD OF MIXING

in wages/hour divided by tonnage is bound to favour the larger plant. Whatever the size, design, or other characteristics the manufacturing plant may possess, it must be capable of fulfilling the requirements contained in the opening paragraph.

The attainment of these requirements is reached after various stages of manufacture have been completed. These stages can be divided into the following items, which are discussed in detail below :

(1) Feeding the plant.
(2) Cold end equipment.
(3) Heating the materials and drying aggregates.
(4) Screens and hot storage bins.
(5) Proportioning and measurement.
(6) Mixing the materials.
(7) Transporting the mixed materials.

Mixing may be batch or continuous. Batch mixing, however, is predominant in this country. Typical layouts of both systems are shown in Figs 4 and 5.

(1) *Feeding the Plant*

Two means are available to feed aggregates to an asphalt plant, the mechanical shovel, or an excavator fitted with dragline equipment. Mechanical shovels have the advantage of being able to pick up and load with considerable selectivity. The most modern versions fitted with a 1 cu. yd. scoop can load 60 tons/hour. The advantage of an excavator with dragline equipment over a mechanical shovel lies in its ability to raise and trim a stockpile. Stockpiling of sand, for example, helps the material to drain and consequently assists in drying. Given equal capacities, the dragline equipment will handle more material than the shovel because of greater economy of movement. As stone and sand are fairly easy materials to handle, the rated output of an excavator can be increased by fitting a larger capacity but lighter weight bucket to the machine.

(2) *Cold End Equipment*

The first sub-heading dealt with handling the aggregates in bulk. Now they must be fed at a controlled rate relative to the output of the plant. Waters [8] has concluded that the equipment for this purpose should consist of divided compartments for separate grades of the aggregate. Experience has undoubtedly proved this to be true. However, it is not only necessary to have separate compartments but also to feed them in a certain order. For example, taking a system which feeds stone and sand from bins on to a common belt, the best effects are obtained by sand flowing from the first bin to provide a carpet for the coarser aggregates. A problem often arises with sand feeding, where excessive moisture or perhaps the nature of the material produces arching over the exit aperture. Fairly steep sides are necessary for the sand hopper with, perhaps, in extreme cases, a vibrator or power ram. Other advantages in feeding from separate hoppers are :

(a) *Temperature Control.* The intermingling of the aggregates prior to entering the dryer will tend to produce a mixture of average moisture content. Therefore, constant adjustments on the heating and drying side are avoided. In the opposing case of a single compartment, the consequences of feeding layers of up to 1 cu. yd., for example, of sand and stone, having moisture contents ranging from perhaps 2 per cent in the case of stone, to 5–10 per cent in the sand, are apparent.

(b) *Smoothness of Manufacture.* Not only is it necessary to feed each size separately, but also to control the proportions relative to the specification. This will result in hot storage bins containing sufficient material without constant waiting. The opposite case of bins overflowing is avoided. The Air Ministry Specifications in particular, which require a gradation of the coarse aggregate, can be successfully complied with only by the provision of cold end bins.

As most Air Ministry contracts are of such a large order that stone has to be taken from several quarries, nominal-sized aggregates are essential to secure the grading specified as opposed to the importation of graded stone. A large number of quarries, when asked for stone to a specified grading, merely load percentages from each bin in layers on to transport. On the asphalt plant this means that, even with divided hoppers, some of the hot bins will be starved whilst others are overcharged. Another weakness of the all-in grading is the segregation of the large particles to the base of the stockpile.

(3) *Heating and Drying of Aggregates*

The heating and drying of aggregates is important for two reasons. The first is a technical one bound up with the fundamental nature of the material, and the second is the economic one, which looks for the maximum heat efficiency. Dryers in asphalt plants are cylindrical in form. They are fitted with liners which assist in passing the aggregates and cascading them through the flame. Heat is provided by atomized fuel oil (Table I) fired through a specially designed burner (Fig 6).

TABLE I

Fuel Oil Used on Asphalt Plant Dryer

Specific Gravity at 60° F	About 0·835 (276 gal to 1 ton)
Flash Point Closed	150° F Minimum
Viscosity, Redwood I at 100° F	Approx 34 sec
Calorific Value Gross	Approx 19,600 B.t.u/lb
Water Content	0·5% Max
Sediment Content	0·1% Max

There is an important distinction between the terms "heating" and "drying." It is a well-known characteristic that some aggregates have a tendency to

sweat moisture even after being raised to the appropriate temperature. Some types of gravel are particularly prone to this behaviour. Therefore, it may be necessary to keep the material in the dryer longer in some circumstances. This may be done by adjusting the angle of the dryer. For example, an alteration of 1° is sufficient to retard the material for ½ minute.

The first lesson which is learnt in dealing with the combustion of fuel oils is the importance of air. It is possible to calculate theoretically the amount of air necessary to provide sufficient oxygen so that the maximum heat efficiency is obtained from the oil. This approach may be satisfactory when dealing with fuel-burning domestic appliances, but under the field conditions in which asphalt plants operate, the position of air vents, prevailing wind conditions, air leaks, and mechanical state of fans may affect the

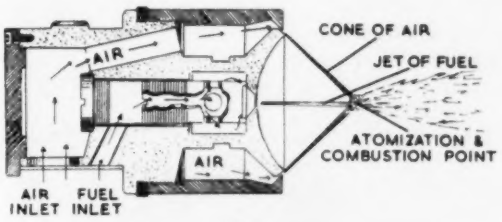


FIG 6

DIAGRAM OF A TYPICAL BURNER USED ON ASPHALT PLANTS

balance of air to fuel. Consequently, heat inefficiencies often arise from incomplete or partial combustion of the oil with a lowering of the calorific value obtained, or alternatively, excess air produces undesirable cooling and stack losses.

On asphalt dryers two types of burner are employed. The first provides sufficient air only to atomize the oil, whilst the second, in addition to air provided for atomization, gives sufficient volume to produce a controlled combustion. This second system offers advantages to the asphalt plant operator, as it gives a positive control of the air supply. A further distinction in design is in the use of combustion chambers. Without combustion chambers there is a tendency for the injected fuel to be blanketed by the falling stone and sand. When they are fitted and suitably lined with refractory brick, the actual burning takes place outside the dryer in a preheated atmosphere and undoubtedly obtains greater thermal value.

The whole question of oil consumption and heat efficiency is an important one to the asphalt industry. For example, heating and drying may take from 3 to 4 gal of fuel oil/ton of material mixed. The saving of only ½ gal/ton on a plant producing 500 tons/day for a working year of 40 weeks is nearly £4000. When a contractor has several plants working this figure can be multiplied accordingly.

A new development in this field is in the use of heavy viscosity fuel oils (Table II) which have been preheated. Special equipment is needed to raise the temperature of the oil to 155°–165° F, where it can be atomized and burnt in the normal manner. The

TABLE II

Properties of Heavy Oil which when Preheated can be Used for Asphalt Dryers

Specific Gravity at 60° F	About 0·935 (240 gal to 1 ton)
Flash Point Closed	150° F Min
Viscosity, Redwood I at 100° F	Approx 220 sec
Calorific Value Gross	Approx 18,800 B.t.u/lb
Water Content	0·5% Max
Sediment Content	0·1% Max

current cost of this heavier type of oil is 1*s*. 3½*d*./gal, as opposed to 1*s*. 5½*d*. for the other material. There is the cost of new equipment to be set against this, together with fuel for preheating. However, when the magnitude of oil consumption is examined it can be seen that small savings soon become quantities of money.

(4) *Heating Asphaltic Cements*

It need hardly be stated here that of all the materials contributing to an asphalt mixture the asphaltic cement is the most sensitive to temperature. Every precaution is necessary on the practical side to ensure that during the handling of the material its properties remain unaltered. The establishment of storage tanks at the shortest possible distance from the mixer is important, together with pipelines at least 2½ inches in diameter.

For many years asphalt cements were heated in "U" type boilers fired by hard fuel. Temperature control is extremely poor by this method, and depends almost entirely on the skill of the stoker. Continual attention is required to maintain fires, and costs are heavy. For use in the field, lagged boilers are desirable, preferably fired by oil, Fig 7 showing modern equipment of this kind. Heating is provided by oil which generates heat through a flue system. Lagging confines temperature losses to 2° F/hour. Furthermore, heating can be provided intermittently and does not require constant attention. Accurate temperature control is possible.

A further advance, relatively new in this country, is the heating of asphalt cements, heavy oil for burners, jacketing of pumping lines, and general heating of the plant by one unit. This consists of a tank containing heavy oil which is heated and pumped at a low pressure through a pipeline which runs through storage tanks and other points requiring heat. The hot oil is then returned to the main storage in a continuous circulating system. By this means all temperature requirements are contained and controlled by one piece of equipment.

The use of lake asphalt requires a special technique. Two points must be borne in mind when dealing with

this material, namely, the need for a homogeneous blend with the flux and the maintenance of the mineral matter in suspension. The material arrives in a solid

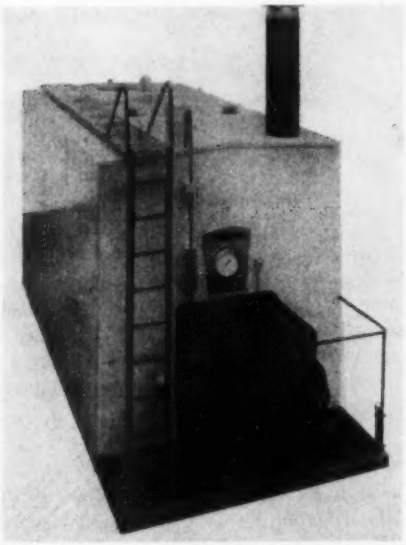


FIG 7

A MODERN TYPE OF ASPHALTIC CEMENT TANK

Oil-fired and lagged, with temperature and volume gauge.

state and has to be broken up before charging into a special tank. The object of this tank is to heat and agitate the lake asphalt so that it is thoroughly mixed. Fig 8 shows a new type of tank which it is claimed will produce a good mixture in a short time. Before production commences, penetration and ash content analyses are essential.

Properly prepared lake asphalt mixtures provide durable and heavy-duty roads. If care is not taken to secure a true blend, the mixed asphalt, when spread on the road, may develop fat, rich, or soft spots, with corresponding dry brittle areas. Finally, as the specification is based on the soluble bitumen content, unless the materials are accurately proportioned and mixed, although the total added quantity of asphaltic cement may be correct, it will not necessarily follow that the soluble bitumen content is in accordance with the limits.

(5) *Screens and Hot Storage Bins*

Problems connected with screening aggregates are generally considerable. The remarks which follow are, therefore, confined to the part played by screens on asphalt plants. In modern plants the horizontal vibrating deck screen appears to be the rule as opposed to the rotary type. In asphalt production it is often the custom to set the burners to maximum and then feed the aggregates at a rate which, according to their moisture content, permits of the highest output. Consequently, screens can be above or below their capacity.

Observation on a vibrating screen will show that if it is underloaded an individual particle of stone is capable of bouncing from one end to the other without passing through the meshes. Fed at the correct rates stones come in contact with each other and are deflected through the screen. On the other hand, overloading produces choking and inefficient separation. It is usual to fit screens of a slightly larger size, *i.e.* one-eighth, than that required in a given bin. When working to an aggregate gradation such as that required by the Air Ministry Specification, frequent bin gradings are necessary.

The Air Ministry Specifications draw the line between coarse and fine aggregates on the one-eighth mesh. As there is no gap grading as in the British Standard, the lowest-sized stone has to be especially watched, as quite frequently "throw over" of one-eighth particles occurs. In some cases, chipping of the aggregate may produce fragments of this size.

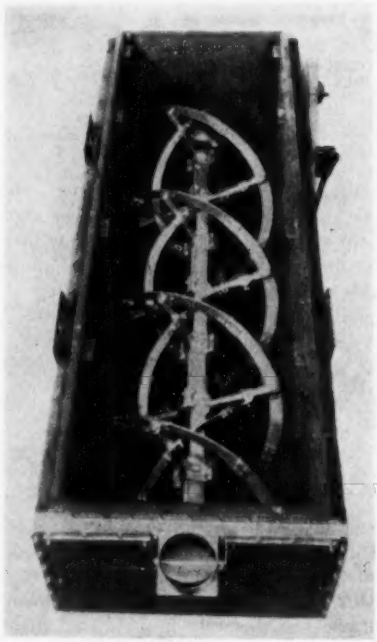


FIG 8

TANK FOR BLENDING LAKE ASPHALT, FITTED WITH HELICAL STIRRING GEAR

In a straightforward combination of stone and sand as required in the British Standard, two or perhaps three hot storage bins are required. For a full grading more are necessary to cover the range. When hot bins are considered, a balance must be maintained between holding sufficient material to

provide continuity and yet not holding so much that temperature is lost. A relationship of the order of a total storage approximately five times the size of the batch is a general indication of capacity. Thermometers placed in the bins are to be recommended, but there seems to be need for apparatus which can withstand the constant attrition of aggregates successfully.

(6) *Proportioning and Measurement*

Starting from the standpoint that provided the proportions of each material in the mixture are those contained in the Specification, satisfactory asphalt will result, it can be easily understood that proportioning and measurement are the most critical stages of manufacture. Most batch plants measure by weight,

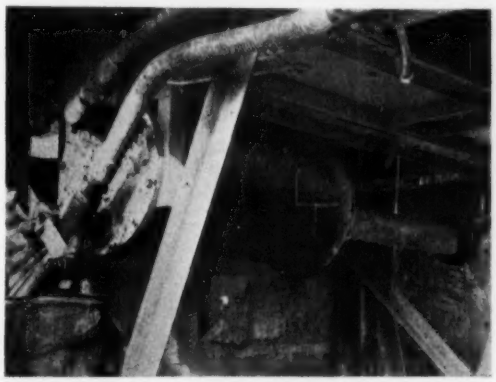


FIG 9

AUTOMATIC APPARATUS FOR PROPORTIONING ASPHALT CEMENTS DEVELOPED BY THE ROAD RESEARCH LABORATORY

Quantity of material controlled by length of piston stroke inside cylinder.

and a variety of scales, yard arms, and balances are in existence for this purpose. The plain fact is, however, that any measuring devices, however satisfactory in themselves, which depend on manual operation, must be suspect as regards producing material which complies with the Specification at all times. Consequently, automatic means of control have considerable appeal.

It is quite well established that of all the materials in the asphalt mixture the soluble bitumen content is the most critical. As it is incorporated in the lowest quantity, considerable care is needed in its measurement. As a preliminary, therefore, a separate scale with fine graduations is necessary. Pre-set or automatic means are inevitable and must evolve as common practice. Figs 9–12 show some examples of equipment in this field.

(7) *Mixing*

Russell,[9] during the course of investigating the efficiency of paddle mixers in commercial use, found

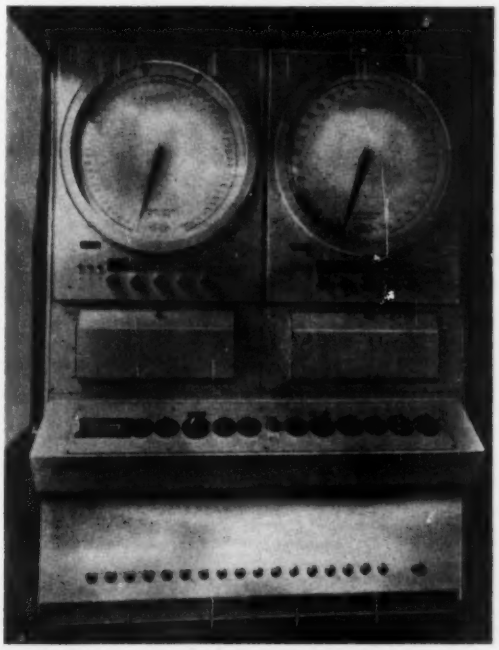


FIG 10

PRE-SET PROPORTIONING CONTROLS FOR AGGREGATES AND ASPHALTIC CEMENT DEVELOPED BY FRED. PARKER AND CO. LTD.

When dial pointers reach pre-set points delivery of materials is instantly stopped.

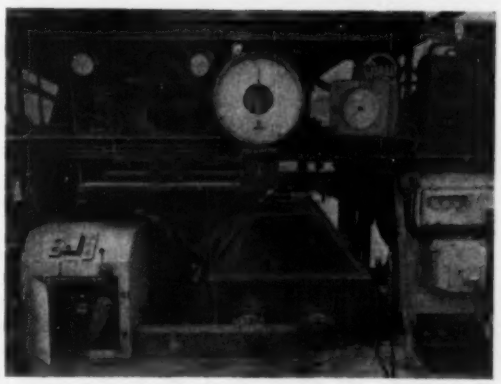


FIG 11

AUTOMATIC AND PRE-SET MEANS OF PROPORTIONING FITTED TO THE "WIBAU" PLANT

Aggregates on the centre dial and asphaltic cement on the right.

X 2

that they varied in capacity to render a batch completely homogeneous. One of the major points to emerge from this work was related to the paddle tip

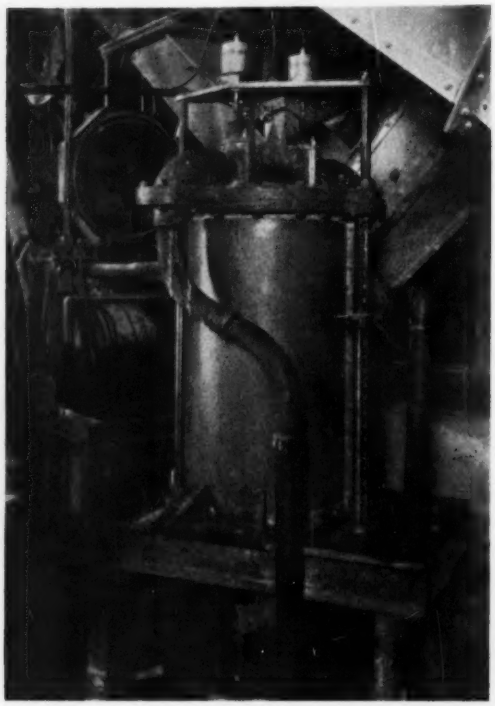


FIG 12

APPARATUS FOR MEASURING ASPHALT CEMENTS DEVELOPED BY STOTHERT AND PITT LTD

Amount (up to 38 gal) automatically controlled by length of piston stroke inside cylinder.

angles. Better mixing was obtained when they were set at a minimum of 30°.

The material used in the research was bituminous macadam. In a more dense coherent mass, such as asphalt, mixing problems are likely to be greater. Instances occur where adding by weigh bucket into a mixture containing a high fines content produces bad segregation. Mixer speeds range from 20 to 75 rev/min. The best distribution seems to be obtained by a combination of the recommended paddle settings previously referred to, operating at 40–45 rev/min. The higher speeds tend to produce fracturing of the aggregate, often reflected as a high fines content on analysis. Adding asphalt cement through a spray bar, particularly under pressure, produces better dispersion. The discharge of the asphalt from the mixer doors has to be carried out so that the mass of asphalt falls as nearly as possible together. A slow, or trickle, emptying will produce segregation, particularly with a high drop.

Filler is usually added to the mix after the asphaltic cement. If it is added before there is a possibility that considerable losses in the atmosphere may occur. Under the prevailing system of adding filler last and, in consequence, mixing it for the shortest time, doubts must arise as to whether it is always adequately distributed. If it is accepted that the function of the filler is to combine with the asphaltic cement to provide stability, it would seem logical to suggest that these two materials should be pre-mixed before addition.

Mixtures contained in the British Standard require added filler of up to 16 per cent. Taking 10 per cent as an average, this means, on a 20-ton/hour plant, 2 tons or 40 cwt bags to handle every hour. Most filler elevators are comparatively small, with limited feeding apertures. Therefore, only one man can really work at that point. If the output goes up to 30 tons/hour at the same percentage, the input rate is one cwt bag/minute. This is nearly the limit of manual handling. On a bigger plant the results of manual handling can only mean reduced outputs.

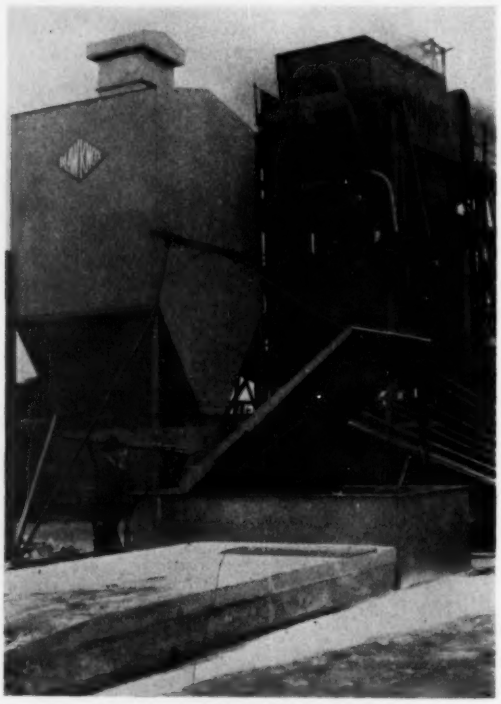


FIG 13

BULK FILLER UNIT OF 30 TONS CAPACITY

The material is transferred to the mixing plant by air blowing.

The use of bulk cement hoppers discharged by air has been a feature of the construction scene for some time past. The principle has now been applied to asphalt plants (Fig 13). Not only does this equip-

ment provide adequate supplies of filler to the mixing point but, being semi-automatic, also reduces labour costs. When it is remembered that the current cost

FIG 14

ASPHALT STORAGE HOPPER FITTED TO A CONTINENTAL PLANT

The mixing section rests on the ground and the mixed material is elevated by skip to the hopper.

of paper containers for filler is 5½*d.* each, or 9*s.* 2*d.*/ton, a further advantage is obtained.

(8) *Transport*

Where lower temperature macadams may be carried in loads of up to 15 tons, asphalt is hauled in 6–7-ton loads to avoid lengthy waits under the mixer, where possible temperature losses may occur. Lorries with metal-lined bodies are preferred for this purpose. They should be capable of delivering into a mechanical spreader without undue discharge on the ground. Protection by tarpaulins against weather is advisable.

The distance which asphalt can be hauled will depend to some extent on weather conditions. Distance as a measurement is somewhat misleading, as the real yardstick is time, which brings in the type of terrain to be covered. Although the main bulk of the asphalt load will retain its temperature for some time, after some 1½ hours noticeable drops will be found on the crust of the material. In a test carried out in March 1956, a double-walled lorry of 4 cu. yd. capacity, with simple wood lagging, carried a load for 9 hours. The material was laid quite easily in the late afternoon.

A snag often encountered in transporting hot asphalt, particularly those mixtures falling within the richer schedules of the British Standard, is one of segregation. This takes the form of a rise of the bituminous mortar to the top of the load through the vibrating action of the journey. This phenomena is not so serious as appears at first sight. Very often the load which is apparently floating in excess soluble bitumen is covered only by a thin crust. Working at the lower end of the temperature ranges will often overcome this problem.

Hot asphalt storage hoppers appear to be part of the basic design on Continental plants (Fig 14). They are not in common use in this country. Provided that practical difficulties can be overcome, such as temperature losses and discharge of the material, there are advantages in their use. Unproductive time standing under the plant can be cut down and less lorries used for each run. Mixing can commence and cease without transport being available. All of these items lead towards lower haulage costs.

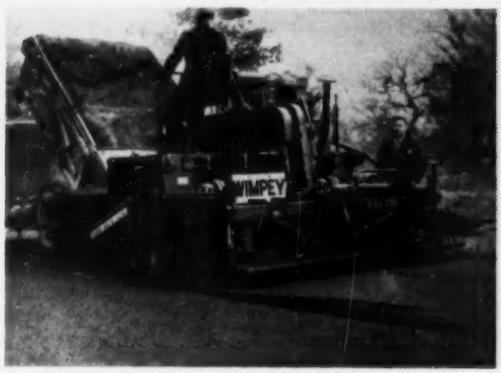


FIG 15

THE BARBER-GREENE SPREADER

General Details

1. Operates on crawler tracks
2. Widths of courses laid—8–12 ft
3. Depths of courses laid—¼–6 inches
4. Forward travel speed—7·85–44·50 ft/min
5. Length 15 ft
6. Height 7 ft 9 inches
7. Hopper capacity 6 tons
8. Capable of laying to a cross-fall or camber
9. Thickness adjustments by vertical screws at the back of the machine
10. Latest modification is to fit road wheels for travelling between sites

THE TECHNIQUE OF LAYING HOT ASPHALT

The object in laying asphalt is to spread the material while warm over a prepared foundation to a specified thickness and level, and then compact with a suitable

roller. In the early days the spreading of asphalt was entirely a manual affair. The development of mechanical spreaders (Figs 15–17) vastly extended the scope of asphalt construction. The advantage of

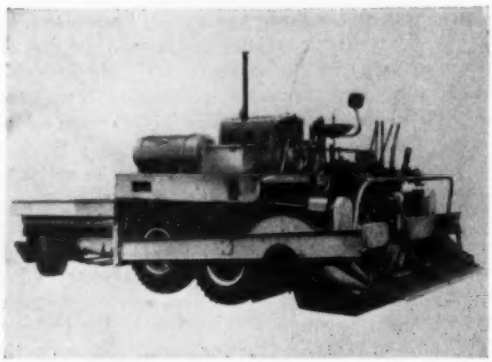


FIG 16

THE BLAW KNOX PF 90 PAVER

General Details

1. Rubber tyred for paving and travelling
2. Widths of courses laid—8–13 ft
3. Depths of courses—¼–10 inches
4. Forward travel speed—4·34–51·01 ft/min
5. Length 20 ft
6. Height 8½ ft
7. Hopper capacity 7 cu. yd.
8. Capable of laying to a cross-fall or camber
9. Thickness adjustment made by hand wheels at back of machine
10. Capable of moving between sites without use of other equipment (*i.e.* low loader)

mechanical spreading is that, properly undertaken, it produces a better job because of its increased scope. That is to say, where hand spreading tends to regard a job as a series of connected lengths, a machine can take a longer view. When the use of a spreader is considered the work should be planned to give continuity. The cost of hauling a spreader, say, 20 miles is of the order of £20–£25. Economically, there must be sufficient area to render this sum equivalent to a few pence/sq. yd.

In common with the manufacturing plant, a spreader operates with the same number of men whether outputs are high or low. Once again, the greater the throughput, the smaller will be the unit cost. At average thickness, mechanical spreaders can lay faster than most plants can produce. It must be admitted that in this country most road contracts do not permit high tonnages to be handled. At the same time, continuity of operation is essential in producing a good surface.

For ideal continuity it is best for the machine to always have a load of asphalt ready to tip into the hopper. If, as an example, a machine is operating at a normal rate laying a 10-ft strip, it will cover nearly 800 sq. yd/hour. Assuming the thickness of the course to be 1½ inches, the output required to keep the finisher moving continuously would be between 50 and 55 tons for the same period. This gives an indication of the outputs which modern mixing plants should provide.

Very often, the best that can be achieved is a compromise between low output plants and higher capacity finishers. One of the most common ways in which this is done is to wait until several loads are available and then commence to lay, rather than allow a long time lag between individual deliveries. In extreme cases of under-delivery, the machine may have to be drawn off and emptied. A series of transverse joints then appears. By leaving asphalt in the hopper whilst waiting for loads, the risk is run of dangerous falls in temperatures, which can have disastrous results on the machine (bent flight bars, corroded screed) and the road (undulations, fretting, and scabbing). Other faults in operation are shown in Fig 18.

A subsidiary to feeding the spreader continuously is the need for keeping it moving in the same manner. The flow gates, for instance, should be adjusted so

FIG 17

THE AMMANN SPREADER

General Details

1. Operates on crawler tracks
2. Widths of courses laid—max 6 ft 9 inches (may be reduced by means of a cut-off plate)
3. Depth of courses laid—¼–5 inches
4. Forward travel speed—3–8 ft/min
5. Length 15½ ft
6. Height 3 ft 9 inches
7. Output 35 tons max
8. Capable of laying to a cross-fall or camber
9. Thickness control by spring-loaded screw feed (seen close to wheels)
10. Retractable wheels enable machine to be easily towed

that the distribution box is always full, and there is no need for frequent stops to pass the asphalt to the back of the machine. Finishers are designed to lay varying widths, so it is necessary to set out lanes appropriate to the job in hand. Where circumstances

Operation Chart for Barber-Greene Finishers	Fluctuating surface texture A	Lean, brown dead appearance of surface B	Rich, shiny appearance of surface C	Brown streaked surface D	Transverse hair cracks in surface E	Surface cracks in centre of strip F	Surface cracks at edges of strip G	Varying surface cracks on surface of strip H	Deep transverse cracks across full width of strip I	Pockmarked surface J	Rough, uneven surface K	Wavy surface (long waves) L	Wavy surface (short waves) M	Bad longitudinal joints N	Bad transverse joints O	Roller marks P	Mat shoving ahead of roller Q	Tamper marks R	Bleeding S	Unsatisfactory compaction T	Poor levelling control of screed U	Water pockets or short low section in surface V	Checking under roller W
Poor plant operation	×	×	×				×	×	×		×									×	×		
Excessive moisture in mix		×															×						
Lack of bitumen in mix		×																		×			×
Too much bitumen in mix			×								×						×		×		×		
Poorly graded mix	×	×	×	×		×	×	×	×		×			×			×		×		×	×	×
Poor bitumen product	×	×	×	×													×			×			×
Segregation of mix in trucks	×										×											×	
Poor control of #200 mesh material	×	×	×	×		×	×	×	×		×									×	×		×
Poor temperature control of mix	×	×	×		×	×	×	×	×		×	×	×	×			×			×	×		
Improper operation of finishing machine					×	×	×	×			×	×	×	×	×			×			×		
Over-controlling of screed											×	×		×							×		
Improper position of tamper bars					×	×	×		×		×			×						×			
End section of screw conveyor disengaged							×	×															
Agitator should be installed									×		×	×									×		
Crawler drive clutches slipping														×									
Crawler take-up too tight													×										
Tamper not up to speed																		×		×			
Finisher travelling too fast									×		×			×			×	×		×			
Loading screw conveyor too heavy											×	×									×		
Worn out screed plate							×	×	×		×			×									
Worn out tamper bars							×	×	×		×			×				×		×			
Screed rests on surface while stopped											×											×	
Allowing roller to stand on fresh surface											×					×						×	
Putting roller on fresh surface too soon					×			×			×	×				×	×					×	
Rolling too fast					×			×			×	×		×		×				×			×
Reversing roller too abruptly											×					×	×					×	×
Water not used on rollers											×			×		×							
Turning roller too abruptly								×			×					×						×	×
Too much slack in roller drives					×			×			×		×			×						×	
Roller too heavy											×					×	×						×
Three-wheel roller used instead of tandem																×						×	
Roller too light														×						×			
Prime or tack coat not used																	×						×
Dusty or dirty base																	×						×
Prime or tack coat applied too heavy																			×				×
Inadequate rolling					×			×			×					×				×		×	
Too much rolling											×					×						×	×
Mix not suited for cold weather application					×			×	×		×			×				×		×			
Mix not suited for hot weather application											×	×		×			×		×				
Unstable mix					×			×			×		×	×		×	×				×	×	×
Soft stone or clay balls in mix										×		×	×	×		×							
Gasoline, kerosine, oil spilled on surface				×						×													
Soft base											×											×	×
Poorly graded base surface											×									×	×	×	
Excessive length of strip														×	×								
Not rolling joint soon enough					×	×								×	×							×	
Screed tension spring too tight											×	×								×	×		
Hydraulic jack not released											×	×								×	×		
Brakes set on truck											×	×	×										

FIG 18

EXTRACT FROM BARBER-GREENE HANDBOOK

permit, advantage can be taken of extension boxes to lay maximum widths and reduce joints accordingly.

The British Standard points out that with some forms of mechanical spreading it may be desirable to use a lower asphaltic cement content than would normally be adopted for hand spreading. This is particularly true of the richer mixtures. On the Barber–Greene spreader the screed unit is normally supported by the material which is being laid. When rich mixes of low stability are spread, the whole of the screed weight can be supported by the spring supports at the back of the machine. A variable tamper stroke is an advantage when handling these mixes.

It will be seen from the British Standard that provided the size and stone content is in proportion, a wearing course thickness of up to 3 inches may be laid in a single course. Whether this is generally possible, particularly in the richer schedules, is another matter. The effects of rolling on thickness and temperature are discussed separately. As a general principle, however, if a total thickness of 3 inches is required, the best results are likely to be obtained by using two-coat work with a wearing course of 1½ inches maximum.

Manual spreading of asphalt calls for a high degree of skill and is used in situations where a spreader cannot operate. An important function of hand work is the pre-regulation of existing surfaces where depressions exist which do not permit the main asphalt courses to be laid within the required tolerances. To be effective, this should be carried out with the use of a level, boning rods, or a camber board. Thickness and areas can then be marked on the road.

(1) *Rollers*

It is usual to specify rollers by weight. This is not entirely satisfactory, because the point is not so much dead weight as applied weight expressed per inch. The latest Air Ministry Specification requires a three-wheeled roller weighing 10 tons with 300 lb minimum per inch of rear wheel. As an example, an asphalt roller weighing 10 tons, of tried performance, with a weight distribution of 65 per cent on the back to 35 per cent on the front, gives a figure of 305 lb on two 24-inch rear wheels, or rolls.

On the other hand, a similar weight roller, operating on two 20-inch wheels, is known to prove unsatisfactory as a result of practical experience. Taking the same division of weight, the pressure per inch of rear wheel in this latter case is 420 lb. Therefore, it seems advisable to impose a maximum limit in this respect. There are two types of roller in common use, *i.e.* the three-wheeled and tandem roller. A three-axled roller is used in America, but the point made previously, *i.e.* applied load, is still the ruling factor.

Whilst a roller must have more weight on the driven rolls to proceed and climb at the same time, to roll a smooth surface the weight applied per inch of rear-driven rolls must be similar to that applied on the front-driven rolls. For example, if 65 per cent of the total weight is necessary to drive and climb in order to obtain equal weight distribution back and front, 65 per cent of the total width must be on the back rolls. Therefore, a three-wheeled roller with a total width of 48 inches on the two rear rolls would require a front roll width of 26 inches.

The front and rear rolls should be positioned so that they overlap in rolling area. If this is not so designed, patterned marking will be apparent, with the possibility of dead areas remaining which have not been rolled. Water sprays are fitted on asphalt rollers to prevent adhesion of the hot asphalt. Uneven water distribution means uneven cooling of the asphalt crust and manifests itself by picking up parts of the surface.

Rolling takes place longitudinally with the heavier part of the machine being applied first, each pass overlapping the other. The first consideration as far as the material is concerned is temperature at the time of rolling. If a roller is put on too quickly, surging in front of the machine is likely to occur. "Flushing-up" is another indication of too high a temperature. Undue marking, cracking, and pushing are other signs. Rolling below temperature will produce an asphalt of poor density, and early fretting is possible.

The speed of the machine and number of passes will have considerable bearing on the finished surface. A speed of approximately 3 m.p.h. seems to give the best results. The number of passes will depend to a large extent on the course thickness. Excessive use of water sprays will produce rapid cooling of the upper asphalt crust. Fine hair cracks will then develop as the roller passes, giving a crazed appearance to the material.

This is also liable to occur if the material is delivered too hot from the plant. In this case the crust is formed by the cooling action of the air. If a wearing course thickness exceeds 1½ inches, a similar uneven temperature drop is likely. Waving of the surface may result. Rich mixtures in the British Standard are very liable to distortion under the roller, particularly if accompanied by these temperature characteristics.

(2) *Raking*

It is generally assumed that the object in raking is to spread the asphalt, but it must be borne in mind that it also finishes the surface. There comes a time during the course of hand spreading when, due to temperature changes, any surface treatment, such as raking, will produce permanently bad results. Score marks from the rake tines or scabbing of the surface are typical effects. Probably the most common

fault is over-raking. This produces pockets of coarse aggregate in the surface which are potential sources of weakness. This is particularly likely to occur on high stone content asphalt.

An interesting point in this connexion has been observed in the behaviour of Air Ministry asphalts where a coarse aggregate gradation is required. The gradation gives the usual series of tolerances on each mesh, but if an attempt is made to work to a smooth grading curve there is a marked improvement in the handling of the material, with a more uniform surface texture.

There will be a limit to the area which can be raked at one time. Therefore, the relationship of this area to the surrounding asphalt must be watched. An inexperienced raker will tend to pull the material towards himself and thereby produce high spots within his immediate vicinity. Side battens of a thickness appropriate to the depth of course being laid by hand are necessary, with due allowance being made for consolidation.

(3) *Evenness of Surface*

The tolerances of surface finish for asphalt wearing courses have shown during the past few years a definite trend towards producing a better standard of riding quality. Most particularly this applies to airfield construction, where high landing speeds of aircraft require an extremely good degree of finish ($\frac{1}{8}$-inch in 10 ft). This is difficult to achieve, and requires special care and attention in working practice. One of the most important requirements in producing a finished surface of this order is that the base, or existing surface upon which the final wearing course is to be placed, must have been laid accurately.

Profilometers and bump integrators are available to test surfaces after completion, but during the course of laying asphalt the straight edge is in common use. Straight edges have their limitations, particularly when working to the $\frac{1}{8}$-inch in 10-ft standard. The best that can be done is to form a team engaged on testing surface finish only. This means two straight edges, one operating longitudinally and the other transversely. They can then be worked in liaison with the laying foreman and the roller drivers. A slight back lash or momentary halt by the roller can easily cause a depression greater than $\frac{1}{8}$ inch.

The best straight edges are of metal and should be used with a graduated wedge. When matching an existing asphalt strip with new material, attention has to be paid to any bevelling or distortion present, otherwise the error will be transferred to the new lane. Clearly, the present method is cumbersome and open to doubt as to its efficiency in achieving the necessary accuracy of measurement. It has been reported * that Hampshire County Council are using a piece of equipment of American design to test the accuracy of surfaces during laying. Further research is needed into this important matter. A form of profilometer constructed around a light frame with low pressure tyres and towed by the finishing machine, would possibly provide a starting point.

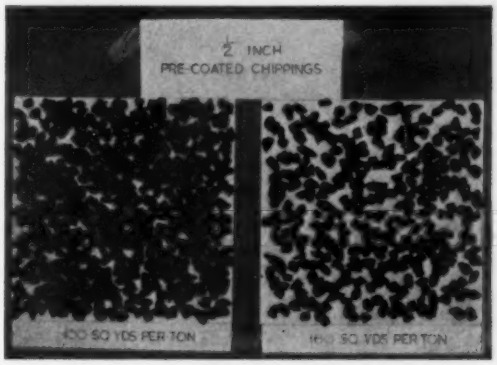


FIG 19
½-INCH PRE-COATED CHIPPINGS (B.S.S. 594)
Maximum and minimum rates of spread

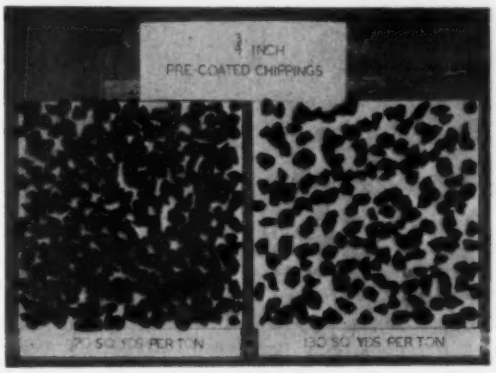


FIG 20
¾-INCH PRE-COATED CHIPPINGS
Maximum and minimum rates of spread

(4) *Pre-coated Chippings*

The British Standard requires that application of chippings pre-coated with an asphalt cement of 40 pen must be spread by hand on to wearing course mixtures containing less than 40 per cent of coarse aggregates.

When these rates of spread are examined (Figs 19 and 20) it will be seen that in the heavier applications the chippings form an almost complete covering on the surface. The lower rates are, in fact, closely akin to a surface dressing treatment. In the absence of a

* *Rds & Rd Constr.*, 1953, **31**, 219.

suitable machine to spread pre-coated chippings, it seems pertinent to ask if these heavier rates are ever achieved in practice. If they are, it is certain that severe bunching and over-riding will occur.

FIG 21

APPARATUS FITTED TO ROLLER CUTTING A JOINT IN AN ASPHALT CARPET

The expressed object of applying pre-coated chippings is to provide a roughened surface. However, in a survey * of roads where skidding was prevalent in wet weather over 80 per cent of the sites studied had surfaces of a roughened nature which might be superficially regarded as "non-skid." Taking two sources from which a road may derive "non-skid" characteristics—(*a*) minute projections from the surface able to pierce the moisture film and provide contact with a tyre; (*b*) the surface characteristics of the projection, *i.e.* smooth, rounded, rough—there seems cause for enquiry as to the value of pre-coated chippings in the "non-skid" sense. In the first case, there is no guarantee that by the present methods the chippings will be so evenly distributed that uniform contact with a tyre is provided, and in the second case, as is well known, some aggregates have the ability to polish, together with possessing varying affinities to bitumen, so that assuming that the first requirement is met, namely, projection above the moisture film, it cannot be argued with certainty that conditions have been provided whereby a vehicle tyre is in contact with a roughened surface.

(5) *Joints*

Correctly-made joints in an asphalt surface can add considerably to the appearance of the road. If they are not correctly made they are possible sources of weakness. Joints in the wearing course are broken, *i.e.* staggered, with those in the base course. The roller should make its first passes whilst the material has sufficient temperature to knit in with the existing asphalt. Painting joints with hot bitumen is specified, but this presents certain practical difficulties in keeping the bitumen warm and applying it evenly.

It is usual to cut back joints between both transverse and longitudinal sections. This may be carried out manually or mechanically by means of a compressor with suitable tools. Fig 21 shows a recently-developed piece of equipment fitted to the roller, which considerably reduces the time involved in this operation.

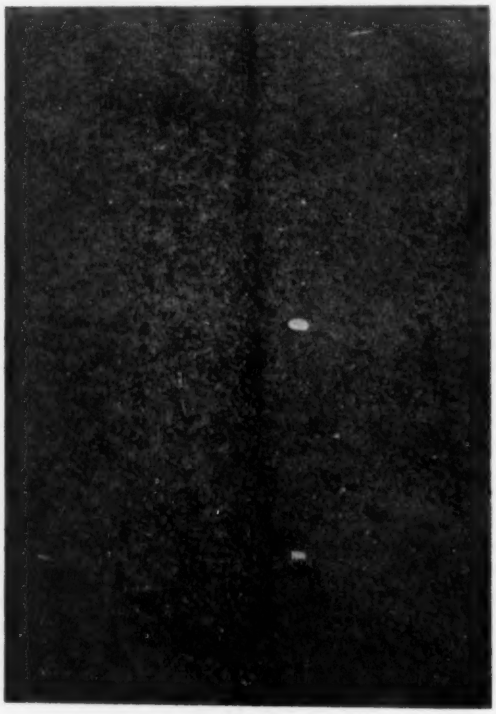


FIG 22

EXAMPLE OF OVER-RAKING ON A JOINT, WITH AN ACCUMULATION OF COARSE AGGREGATE

* Sabey, B. E. *Rds & Rd Constr.*, 1956, **34**, 203.

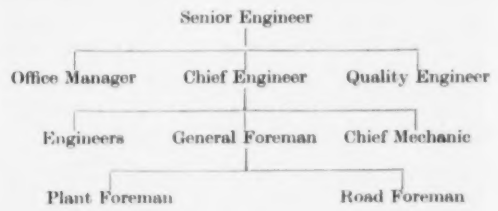
When operating the Barber–Greene spreader it is recommended that the screed overlaps the existing asphalt strip by up to 4 inches. The object is to produce a good union, but if carried out to this extent on a cold joint, the screed scrapes the existing asphalt so that the joint is always visible. Over-raking on joints is especially dangerous, particularly where coarse aggregate particles are drawn to the edge of the strip (Fig 22). Any such accumulations should be scattered back towards the centre.

THE LARGE-SCALE CONTRACT

A large Air Ministry contract may require asphalt tonnages in the order of 50,000–100,000 tons. Strict time limits may be specified for all phases of the work, together with its total completion period. Preparatory works are often required, and the assembly of a works programme is essential to integrate the whole contract. The first administrative step requires that the site office be supplied with the appropriate contract documents, such as specification, scope of the work, bills of quantities, and sources of raw materials.

(1) *Staff*

A large contract of the type mentioned may have a total number of 50 on the asphalt side. There will be wide variations plus or minus on the figure, but a typical staff set-up, not including manual labour, is as follows :



(2) *Plant*

A suitable plant site will have to be found. This will have to take into account the following :

(a) *Area Available.* The plants shown in Figs 4 and 5, together with their ancillary equipment and stockpiles, will require an area of approximately 3000 sq. yd.

(b) *Position Relative to the Work.* This will be as near as possible to facilitate control and reduce haulage costs.

(c) *Relationship to Occupied Dwellings.* Dust nuisances are an ever-present problem on asphalt plants.

(d) *Condition of the Ground.* Aggregates should be placed on firm ground to avoid contamination and loss, whilst the plant will require a sound foundation for erection.

(e) *Prevailing Wind.* The plant should be sited in relationship to the prevailing wind to the advantage of the dryer.

(3) *Materials*

Production of 500–1000 tons/day is sometimes required to meet contract completion dates. The intake of materials therefore assumes major proportions. Forward planning is essential to ensure that when a change is made from base to wearing course, sufficient materials are available. On the other hand, too large a stockpile of stone, *e.g.* 2000 tons, may result in segregation. Constant checking for quality has to be maintained, particularly on sand, as the natural layers become exhausted.

(4) *Practical Organization*

Practical organization will vary widely from contract to contract. A broad guide, however, is as follows :

(*a*) Approval of samples of raw materials, agreement on works programme and plant by the employing authority.

(*b*) Assembly of the contractor's site organization, including offices, plants, and labour.

(*c*) Setting out the work, *i.e.* preliminary surveys, plotting finisher lanes, and the general form of the work.

(*d*) Drawing up of progress charts relative to the programme.

(*e*) Calibration of plant and experimental mixes.

TECHNICAL CONTROL

The testing of asphalt materials in the laboratory, particularly under production conditions (Fig 23), has always been part of asphalt manufacturing procedure. With plants increasing in capacity, however, the potential ability to produce good material has to be balanced against the other possibility of mixing a large amount of asphalt which is not in accordance with the specification. Faults, such as scales getting out of adjustment and blocked or perforated screens, are comparatively small matters which can result in trouble on the road.

Employing authorities usually direct in the clause dealing with testing that the British Standard [10] for sampling and testing shall apply. There are two methods of analysis contained in the Standard, the funnel method (B.A.1) and the hot extractor (B.T.1). Gough [11] points out that method B.A.1 may take 2–8 days to produce an analysis, whilst this time is

shortened to 3–8 hours for B.T.I. It is quite apparent, therefore, that the basis of testing on which most contracts rest is useless for practical purposes. Even the more rapid of the two methods given above has certain qualifications as to its accuracy.

As a result of these inadequate means of analyses the contractor has to rely on one of the several rapid methods available. The Road Research Laboratory method, for example, can give a complete analysis in 1–2 hours. This form of analysis is included in the standard methods of testing of the Institute of Petroleum. It will also be incorporated in the revised British Standard. At the moment, however, and for a considerable time past, any analysis carried out by rapid methods where the British Standard is part of the contract conditions is not strictly admissible.

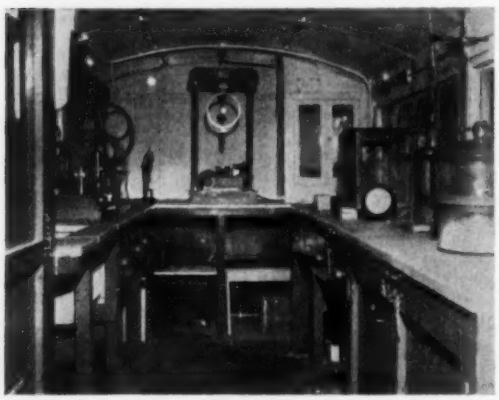


FIG 23

INTERIOR OF A FIELD LABORATORY SHOWING ROAD RESEARCH LABORATORY RAPID METHOD OF ANALYSIS (*left*) AND MARSHALL PROVING RING (*centre*)

The periodicity of sampling and testing, together with interpretation of results, is a matter often debated. Good control is usually considered to be one sample/100 tons. This leaves aside any cross-checks on the accuracy of the chemist engaged on the routine analysis. The British Standard directs quite clearly on the matter of sampling. Discussions on quality based on analyses results are often obscured by the fact that samples have been taken incorrectly. Sampling during manufacture has the advantage of permitting the sample to be built up by increments and duly quartered. However, in cases of dispute involving comparative analyses some disturbing differences in results are occasionally noted.

After many years of discussion in this country regarding mechanical analysis of asphalt, a test in the form of the Marshall Criteria is now part of Air Ministry asphalt procedure. It does not fall within the scope of this paper to discuss the technical value of the Marshall or any other mechanical test. At the same time, routine testing, for example, in respect of the parallel construction material, concrete, gives information to the engineer which is related to performance. Where routine asphalt analyses are concerned, a comparison is made between the constituents of the mix and the specified tolerances. Provided that the analyses show compliance in that respect, the engineer is entitled to assume that the asphalt will be satisfactory for the purposes intended. It can be appreciated, therefore, that the engineer has to take a certain amount of performance ability on trust—an outlook not usually associated with civil engineering or building design.

The Quality Engineer

Although considerable stress has been laid on the need for routine analyses from many quarters, the whole point of technical control is lost unless the results are practically applied. The establishment of a laboratory and methods of sampling and testing are, therefore, only part of the picture where quality is concerned. Furthermore, asphalt construction in the quality sense embraces not only the material but also the finished road or runway and, therefore, covers plant and laying control.

Because a chemist may have excellent qualifications and also be an accurate analyst, it does not necessarily follow that he will be a quality engineer in the full sense of the word. Not only must the quality engineer have technical knowledge in respect of testing, but also the ability to take action on the manufacturing plant and spreader. Finally, a personality of a type capable of conveying the technical implications of the contract to staff at all levels is essential.

EXAMPLES OF ASPHALT CONSTRUCTION

(1) *Laying Asphalt in Layers to Specified Levels*

An interesting application of asphalt is in its use as a means of strengthening and regulating an existing runway by laying the material in layers to a given O.D. level. The means by which this is achieved is to first chain the runway and then divide it into suitable finisher lanes. The chainage points are then extended across the runway to form a grid. Levels are taken at the intersecting points and plotted on squared paper. The new levels are placed above and the required thickness calculated. These thicknesses can be painted on the runway at the appropriate points.

It may be found during the course of this close gridding that high spots, undisclosed in prior surveys, are present. This will mean removal or a general raising of the levels. The specification will give direction on the maximum thickness to be laid in one

layer (usually 3½ inches); therefore if a wearing course of 1½ inches is required, any places which exceed 5 inches will have to be treated separately. These areas may occur quite locally, and in some cases can be treated by hand. As each course is laid, levels are taken, so that the final wearing course [6] is accurate to within 0·01 feet of the new level.

(2) *Feathering (in Depth) of Newly Raised Surfaces*

New construction on runways may not always cover the whole width, so it is necessary to feather out the new pavement (which may be 8½ inches in thickness at the edge) into the existing runway. It may be, however, that the old surface is not in the same relationship, as regards level, to the new work down the whole length of the new construction. Depending on this relationship will be the extent of the feathering construction and consequently its depth.

It is thus necessary to take levels at intervals along the edge of the new work and then calculate the distance required to produce the required fall to the old runway. This will produce an irregular line and the area so delineated will have to be levelled to determine if any high or low spots are present. Laying of base coat can then proceed, with levelling taking place on each course. The depth and extent of each layer is controlled so that the correct thickness of wearing course can be applied. The two foregoing examples have been carried out with asphalt to the Air Ministry Specification.

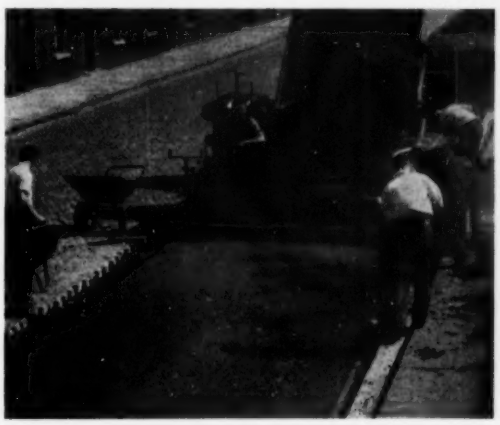


FIG 24

REPLACEMENT OF GRANITE SETTS BY ASPHALT IN BELFAST

(3) *Reconstruction of City Streets in Belfast*

The City of Belfast has, over the last few years, pursued a policy of progressively removing old granite sett streets and replacing with asphalt. The last major contract of this type involved the city's main thoroughfare and industrial districts. The setts were removed and replaced with base course (Fig 24) in thicknesses up to 4 inches, followed by a surface coat of 1½ inches. Both materials were in accordance with the British Standard. Over 110,000 tons were laid in this particular scheme.

FIG 25

WIDENING AN EXISTING ROAD WITH GRAVEL ASPHALT

A base course will be applied overall and finally surfaced with a wearing course.

(4) *Tram Track Abandonment (South London)*

With the removal of trams south of the Thames, a major reconstruction scheme involving the removal of tracks and replacement with bituminous materials was launched. Nearly 1,000,000 sq. yd. were dealt with in this project, equivalent to 205 miles of single track. Part of the asphalt work was carried out under direct control of the London Transport Executive, who were responsible for 20 per cent of the total area being carried out in two-course asphalt (3–3½ inches thick) in accordance with the British Standard. A good deal of the remaining area was carried out by the local authorities through whose districts the scheme passed. Asphalt was extensively used in these cases.

(5) *Reconstruction of War Damaged Roads in East Anglia*

Swift [12] has given a detailed description of the development of gravel asphalt in East Anglia. The use of the material continues in that area to a considerable extent each year. It is used for re-surfacing and widening existing carriageways (Fig 25) using base and wearing course material. The first specification for this material was developed by the Ministry of Transport, but with the publication of Parts 3 and 4 of the British Standard, the material is now manufactured in accordance with its terms.

ACKNOWLEDGMENTS

The various illustrations in this paper are published by kind permission of the following: Fred. Parker

and Co. Ltd., Leicester (Figs 1, 2, 4, 10); Pegson Ltd., Coalville, Leicester (Figs 3, 11); Jack Olding Ltd., Hatfield, Herts (Fig 5); Urquhart's Ltd., Perivale, Middx (Fig 6); Cartem Ltd., Westminster, London, S.W.1 (Fig 7); Municipal Appliances, Preston (Fig 8); The Director, Road Research Laboratory (Fig 9); Stothert and Pitt Ltd., Bath (Fig 12); Blaw Knox Ltd., London (Figs 13, 16); David Roberts Ltd., Birmingham (Fig 17); The City Engineer and Surveyor, Belfast (Fig 24).

Acknowledgment is also made to the Director of Works, Air Ministry, for permission to refer to parts of the Air Ministry Specification.

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DISCUSSION

A. W. Jarman: It was very gratifying to read in the first paper that the quality of the bitumen supplied to this market for many years has been so good that it has provided little scope for research work, although this gratification is a little diminished by the advocacy of additions of materials to improve its rheological and wetting properties and to reduce its durability.

There is a reference to the relationship between viscosity and penetration of bitumen, but this does not appear to be a great novelty, because it may well be associated with the penetration/softening point relationship which is normally described as the Penetration Index. In the table showing the relative viscosities of different types of bitumen, a comparison is made between Californian and Mexican bitumens, but the latter was, I think, a fluxed blown Mexican bitumen produced as something of a freak for the particular road experiments upon which the R.R.L. were then engaged; it was not typical of the Mexican bitumen as previously supplied. There is a statement about the high temperature coefficient of viscosity of bituminous binders, but I cannot think of any other binder of this class which has a significantly lower coefficient than bitumen. It is stated that in the U.S.A. asphalt road surfacings show considerable cracking in spite of the fact that they are made with bitumen softer than currently employed in the U.K. This would seem to imply that the stiffness of the bitumen is not the determining factor.

The merits of incorporating rubber in bitumen binders still seems somewhat controversial. In a recent edition of *Road Abstracts*, which is circulated by the R.R.L., there is a reference to a paper given in the U.S.A. which includes the following phrase: "It is concluded from the analysis that about 90 per cent of the potential reflection cracking will take place within five or six years: this appears to be true whether or not rubber additives were used in the mix."

The influence of the viscosity of the cutback bitumen on the efficacy of the wetting agent is an interesting hypothesis, but it would seem possible that the viscosity itself may have some influence on the initial wetting of the stone.

A question which I would like to pose to the authors is the very vexed one of the prevention of stripping in bituminous surfacings. The paper is very positive that stripping can be completely prevented by the inclusion of a percentage of hydrated lime or Portland cement, together with some acid constituent in the binder. It goes on to say that an alternative proposed system in which 10 per cent of tar is included in the bitumen binder is not so satisfactory. I should be grateful if we could be informed of the extent of the practical evidence on which these statements are made. I have seen a publication claiming that the incorporation of an appropriate proportion of Trinidad Lake asphalt can virtually eliminate stripping problems, and I should like the authors to comment on this.

Included in the section on durability is a reference to the behaviour of the binder in fine cold asphalt and the sealing of the surface which takes place with this material; in this type of surfacing it is the usual practice to use a very soft binder, so the question of hardening would appear to be of much less significance.

The merits of increasing the rate of weathering of the bitumen in rolled asphalt is an interesting subject, but it seems that there is still some factor in the behaviour of Trinidad Lake asphalt which has not yet been determined. I suggest that it might be related to the influence of the filler, with particular reference to its possible water absorption.

It is interesting to note the long life of bitumen macadam made with as hard a bitumen as 50 Penetration, because softer binders would normally be employed for this type of work. Could the authors give their opinion on the effect of adding tar or pitch to binders used for open-textured surfacing, in view of the increased rate of weathering which this might introduce?

Mr Leaver's paper is a very interesting disclosure of the know-how which contributes so much to the road-maker's skill. Perhaps I might be allowed to query the nomenclature in describing as hot asphalt that which is, I believe, normally called rolled asphalt.

I should like to ask Mr Leaver to discuss the desirability and necessity for the great variety of asphalt

compositions which are at present encompassed in British Standard 594.

Later, Mr Leaver refers to the fact that in certain wet conditions it is desirable to use an impervious rolled asphalt. The implication might be that asphalt for city streets is not so impervious, so perhaps he would like to remove any ambiguity which this may cause.

I would also like to ask him whether he would comment on the relative virtues of batch and continuous mixers and to amplify his remarks on mechanical *v.* hand-spreading to include the relative costs.

Dr A. R. Lee: We admit that the figures put forward to indicate how the viscosities of different bitumens of the same penetration vary are old ones. At the same time, we thought it might be well worth bringing it to the fore, because it does offer some explanation of the point Mr Jarman spoke about, which is that it is the flow characteristics of the asphalts which may differ as much as ten times when they are made with two different bitumens, those two different bitumens having two different degrees of non-Newtonian flow.

We need to have more experience with the Dutch work on the question of stiffness, in which a method has been put forward for giving a quantitative measure to it. It is interesting to know of the cracking which takes place on U.S. roads, but cracking is only one of the special characteristics of American asphalt. Deformation and wear are others. In 1949 I saw, in the city streets of Washington, cracks which were literally 2 inches wide covering the base formation, a situation which would not be tolerated in the U.K.

I also saw, at one traffic stop, the white line which marks the place where all the motor cars must stop actually bent back by a distance of a foot, due to the force imposed by vehicles when starting. It does not require any great science to explain the defects of that type of work.

A further question was whether the filler might have an effect on durability by adversely affecting adhesion in the presence of water. There are some results in which tests were carried out by the firm which specializes in Trinidad asphalt. Various sections of carpet with Trinidad asphalt were laid on the bed of a river. These experiments have given very remarkable results. The Trinidad, containing its own particular filler, has stood up remarkably well under the action of water. This may not be the final answer, but it does suggest that adhesion breakdown cannot be an effect of any major importance in the production of the special surface texture of rolled asphalt made with Trinidad asphalt. The effect of increasing the oxidation of the binder so as to get a weathering action on the surface is one which will in time become more and more important. With motor vehicles now travelling at high speeds, and with much more powerful brakes, skidding is a problem which is going to become much more important in the future than it is to-day. We shall be faced with the problem of providing non-skid surfaces probably at a much higher and consistent value than we have done so far.

J. H. Nicholas: On the question of the value of adding hydrated lime, and whether it always gives the right answer, all I can say is that every time we have examined carpets containing this material, we have not found stripping, although with the normal constituents of the carpets in those circumstances, in the absence of hydrated lime, a considerable amount of stripping would be expected. When tar alone is used as an additive, we have found an improvement, but it does not provide a complete solution to the problem, as some stripping may still occur.

P. C. Leaver: In regard to terminology, the material is called hot asphalt on the contracts, and as the paper is presented from a practical standpoint, the expression is used.

As far as British Standard 594 is concerned, although the number of possible mixtures, or combination of basic materials, is considerable, in actual practice only a relatively small proportion of them are used in the normal run of road construction. I take the line that an asphalt mixture should be selected in the light of what is required from the construction point of view. The only yardstick available, in road work at least, is that of experience. The question which continually poses itself is whether this approach is really satisfactory, as traffic conditions are changing so rapidly. For example, the present British Standard was published in 1950, based on experience of some years previously. In 1946 there were three million motor vehicles on U.K. roads, and in 1954 six million. So the graph is rising steeply, and this only covers numbers—speed and gross weights have also increased. Can it really be accepted that the British Standard asphalt mixtures are suitable for all these conditions? Alternatively, have asphalt roads been enormously over-designed in the past, or are they under-designed now? It might be of value, in a redrafting of the Specification, to give an indication of the constructional scope of an asphalt mixture. Taken in conjunction with prevailing and future traffic conditions, it is quite likely that suitable mixtures would be limited considerably.

In regard to the use of the term "impervious" to hot asphalt, I am tempted to answer this question in the manner of George Orwell and reply that "All asphalts are impervious but some are more impervious than others!" The point is, however, that under cold, wet conditions it is desirable to present to the elements a surface which is as closely knit as possible. This is in distinction to an asphalt containing a high stone content, with a consequently lower quality of soluble bitumen. These high stone mixtures are liable to segregation, which is sometimes aggravated by over-enthusiastic raking. Patches of coarse aggregate then appear in the surface, very often at joints, and, under conditions of heavy rainfall, water accumulates at those points, and surface fretting or joint disintegration may follow.

The question of the relative merits of the two types of mixer is interesting, and one must remember that the mixer is only half the consideration in asphalt construction. The other half is the potential of the laying machine, which brings in the type of site where the work is taking place. A continuous mixer has the advantage of very large outputs capable of keeping an asphalt spreader moving continuously. In addition, being controlled by a metering pump and a gradation unit, it is free from the human element in proportioning. I have found that the continuous mixer works best on large-scale construction, where it can work as its name implies—continuously. A point that needs watching on this plant is that, as it works on volume translated back into weight, upon which most specifications are based, the stone grading has to be fairly constant, as it is possible to get the correct volumes from the gradation unit but a variation in unit weight if the grading alters. It has been said that one of the disadvantages of a continuous mixer is that it is not possible to hold the material in the mixer for a long period, as would be the case with a batch mixer. By adjusting the form of the

paddle arms and paddle tips, it is possible to mix for well over 3 minutes in a continuous mixer. If an asphalt requires longer than this, the specification must be suspect. A feature of the Barber-Greene plant is the cold end equipment of three or four separate compartments. This is relatively uncommon in the U.K., but assists enormously in keeping a balanced production. This plant also has the combustion chamber type burner mentioned on p. 258. The burner itself is of American design and is very efficient from the fuel consumption point of view.

Batch mixers are more flexible in their use. The Parker "Starmix" is particularly suited to the large-scale contract, and comes reasonably close to balancing output with the throughput of the spreader. The work that Frederick Parker has done in the field of automatic proportioning, as applied to batch mixing plant, is very impressive.

Summing up, the continuous mixer works best under conditions where it can operate without frequent breaks and get rid of its outputs, *e.g.* airfields. A batch mixer can change over mixes more easily and relate its output to each job as it comes along, *e.g.* street work.

The question regarding the cost of mechanical and hand spreading is a little difficult to answer. The actual cost of the laying gang, including plant hire, will be roughly equivalent and will amount to about £25–30/day. The question now arises as to the figure by which to divide this sum. It may be 60–100 tons/day for the hand gang, or up to 1000 tons/day for the machine work. One of the most common pitfalls encountered with regard to mechanical spreading is that the machine seems to be regarded as an extension of the hand laying process. Machine work requires a distinct technique and involves a different understanding of the problem.

C. F. Jackson: In the first paragraph of the introduction to the paper by Dr Lee and Mr Nicholas, reference is made to the variability in the properties of bitumens depending on crude source. I would like to emphasize that rheological and other property requirements can be controlled by choice of manufacturing process and that it is a mistake these days to think too much in terms of geographical origin.

There is a small point concerning a road in Scotland on which I would like to question the authors. This asphalt, made with a blown type bitumen, was found to be "considerably less durable" than that made with normal type bitumens, and I would like to know the criterion of durability in that case, and what the authors meant by the word "durability."

Dr Lee and Mr Nicholas say something to the effect that rubberized bitumen gives an asphalt more resistant to fracture. It would be very interesting to know what is the least amount of rubber which, in practice, will show such an advantage.

The authors say, "Stripping also appears to be a common phenomenon in macadam base courses." Am I right in saying that stripping occurs in base courses coated with tar as well as in those coated with bitumen?

It would seem surprising that the initial penetration of the Trinidad asphalt-based binder was as high as 195 and 192. I was wondering whether if we put, for instance, 50 per cent of diatomaceous earth or a little silica gel into 200 pen bitumen, what sort of results would be obtained in comparison with those using the Trinidad material.

Mr Jarman has referred to the matter of "mucking up" durability by addition of tar. This would certainly seem to be a retrogressive step, and I would like to suggest that what is wanted is not to reduce the durability of the bitumen, but so to construct the road that the binder does not flush up to the surface. In this way the phenomenal durability of asphaltic bitumen could be retained.

Early on in his paper, under bitumen macadam, Mr Leaver said that whereas natural rocks, slags, and gravels can all be used satisfactorily with soft bitumen, the use of gravels with cutbacks is not recommended. A long time ago, I well remember efforts to make gravel macadam with cutbacks, and presumably they were not successful. I would like to ask Mr Leaver whether he has any idea why a gravel macadam cannot be made with cutback bitumen.

Dr A. R. Lee: We must admit that blown bitumen is a problem, and it is a great pity that we and other people have not done more work on the use of blown bitumen. It may be that other people have done a lot more work on it and we have not heard about it. If that is so, we would certainly like to know more about it. In our experience, however, the dense asphalts made with blown bitumen are less durable in that they disintegrate at a much earlier stage. Their final condition is one in which the pre-coated chippings come out, and the mortar disintegrates and wears away rapidly. The Scottish experiment was done in Scotland simply because it was a place where we had an opportunity at that time to lay the experiment. We did, as we normally do, cover a range of bitumen contents, but even the highest bitumen content used, which was much greater than for normal bitumen, also disintegrated within a short time, maybe four or five years, and it had to be replaced.

The filler in Trinidad asphalt certainly does have a bigger effect than the normal fillers used for stiffening the bitumen. I cannot really say how it would compare with a diatomaceous earth, or others of those special fillers which have voids within the particles.

In regard to the retrograde step that Mr Jackson thinks has been suggested, the hot rolled asphalts that Mr Leaver has been talking about are very durable materials. Their average life is of the order of 20 years, and cases are known where they can be much longer that that. They are to be dense materials, completely impervious, and of this long-life durability. To combine those properties with a permanent high skid resistance is a difficult thing to do, and the proposal now made is one way of achieving that object. It is not a question of reducing the durability of the whole carpet; it is the problem of producing surface effect which will add one other advantage to that material.

P. C. Leaver: Gravel aggregates, generally speaking, show a tendency to strip under traffic very rapidly, and I would say that it is advisable to have the strongest possible bitumen film.

Gravel does not usually have the same degree of mechanical interlock as a crushed rock or slag; therefore it is necessary to provide a bond in the form of a sand mortar, as well as protecting the coarse aggregate. Some of the mixtures in the British Standard for gravel macadams require up to 40 per cent of sand. Therefore the manufacturing process is a much hotter one compared with other macadam production. This is another reason why cutback bitumens are excluded.

J. H. Nicholas: We have found severe stripping in tarmacadam base courses quite frequently.

J. F. T. Blott: I would like to refer to the fracture of the bitumen away from the stone in some cases. We

have found that if the stress is built up uniformly over a period of, say, 0·01 sec until fracture occurs, then that fracture always occurs in the bitumen itself, and not at the bond. It is mentioned in the paper that if the stress is built up very rapidly fracture can occur at the bond between the bitumen and the stone. Does that mean that it is breaking by impact, and would Dr Lee think that the fracture in that case may be due to shock waves, and not a simple matter of the development of a stress exceeding the tensile strength of the bitumen?

I would like to ask a question about the veining which occurs on the hot rolled asphalt when it is in a slippery condition. I have observed this veining myself and wondered whether it corresponded with some sort of incipient cracking in the asphalt beneath, or whether it was merely a pattern in the film of the binder on the surface which was generated by the passing wheels; in which case the pattern should change from time to time. Perhaps Dr Lee has some evidence as to whether this pattern does correspond with some structure in the mix underneath. This veining, or rather the flushing-up, is, I suppose, partly due to compaction of the asphalt under the traffic.

Mr Leaver said very little about compaction of the asphalt by rolling. Is it possible that if the asphalt were better compacted initially, some of this subsequent fatting-up would be prevented? Has he any views on the best way of compacting asphalt and whether perhaps some new devices are necessary in order to get the state of compaction initially which is now reached after some years under traffic?

Dr A. R. Lee: The reference to the breakdown of the adhesion at the interface was to experiments under shock. It was definitely that type of experiment where the bond was broken by a falling pendulum and, under that type of impact, the failure did occur at the interface between the bitumen and the solid surface.

J. F. T. Blott: May I ask whether you think that type of action does actually occur in practice on a road?

Dr A. R. Lee: No, I do not think it occurs on a road. In regard to the veining effect, we are not sure of that explanation. It looks as though it is probably due to the movements in the surface. There is a difference. There is almost a skin effect, a hardening of the surface, and a soft layer immediately beneath. The movement, the expansion and contraction due to temperature changes and traffic movements, might easily cause that sort of pattern.

P. C. Leaver: It was a little difficult to find out a lot about rolling in the technical sense. In asphalt construction I always consider the two most important men are the roller driver and the man who operates the back end of the mechanical spreader. The whole question of rolling needs further examination, particularly in the light of optimum compaction values for a given mixture. The question of fatting-up, in its relationship to rolling, is an interesting matter because, to some extent, it brings in the question of mix design. As far as British Standard asphalt is concerned, the important matter of aggregate gradation is specified very loosely. This means that voids contents can vary, although the soluble bitumen content can remain the same. If there is soluble bitumen in excess of that required to coat the aggregate and partly fill the voids, the asphalt may be likened to a sponge—the more it is squeezed, the more it gives up its liquid. Whether this squeezing is done at the time of the initial rolling, or subsequently, as part of traffic action, will control the time when fatting-up will occur.

On the general question of rolling, the latest Air Ministry specification requires certain minimum compaction values based on laboratory-prepared samples. Whether these are obtainable I cannot say, because we found great difficulty in producing the true effect of a roller in the laboratory. If this problem could be overcome it would probably answer the last part of the question. Rolling technique has been developed by rather hit-or-miss methods, and that is why I queried the Air Ministry procedure of specifying certain minimum weights of roller. Because a roller is heavy it does not mean that it is going to compact and give a good road surface. The weight has to be evenly distributed over the roller so that bumps and waves are avoided. A further point is that with heavier traffic it is quite likely that the thickness of asphalt courses will increase. This gives rise to some questions, *e.g.* is an inch of asphalt rolled in the same way as 3 inches? Laboratory tests could possibly provide some of the answers.

N. B. Bourne: Referring to the first paper by Dr Lee and Mr Nicholas, I would like to ask whether the "concept of stiffness" is, as would appear, comparable to Young's Modulus? If this is the case, it is of interest to compare the maximum value suggested by van der Poel of 10^5 kg/sq. cm., as against a mean value for concrete of about 5 times 10^6 and of 30 times 10^6 for steel.

On similar comparison of tensile strength, the 30 kg/sq. cm. quoted by Dr Lee and Mr Nicholas for bitumens would compare with about 40 for concrete, although it is suggested that "with high filler content strengths up to 100 kg/sq. cm. may be obtained," so that tensile strength of asphalt appears to be well in excess of that of concrete. The phenomenon of change of stiffness as a function of time is, of course, similar to the well-known problem of creep in concrete. The major difference seems to be in the fact that temperature has a major effect on asphalt, whereas it has little or no effect on concrete.

Could the authors explain why in airfield work in the U.K. it is the practice to use softer asphaltic cement than that used on roads, in spite of the fact that a high resistance to shear and flow is required? This is particularly striking when on most airfields in Britain to-day the base courses have been built up to considerable thicknesses, and so should be free from movement, although the damp condition of sub-bases may often leave a good deal to be desired.

Could the authors of the first paper tell us whether the distribution of asphaltic cement in hot asphalt is in the form of a film of even thickness over each particle of the aggregate, and whether the thickness of this film is dependent on the quality of the bitumen or on mixing temperatures of stone and binder? Does this also apply to filler particles, or, on the contrary, do these in fact fill the bitumen and therefore increase the volume of binder available for coating? Has the finer mineral matter in Trinidad Lake asphalt a different behaviour from that of added filler mixed with residual bitumen?

Referring to Mr Leaver's paper, it appears that on roadwork, the only generally accepted specification is B.S. 594, and, as he pointed out, the possible choice of mix within the specification appears to be open to as many permutations and combinations to get results as the football pools! Would Mr Leaver confirm that it is possible within B.S. 594 to find sand gradings which provide an unworkable mix? This difficulty would seem to be overcome by the Marshall method of mix

design, which, by trial and error, determines the characteristics of possible mixes with the aggregates available on each site.

Would the author consider that the close adhesion to British Standards is delaying progress in asphalt design, in a way similar to the restrictions imposed by codes of practice on reinforced and pre-stressed concrete design? There does not appear to have been any major advance either on the Continent or America, and no doubt information from Russia is not available.

The arbitrary selection of a stone content for each mix is in curious contrast to concreting practice, where maximum density is nearly always the criterion, with a resultantly high stone content. There would appear to be every argument in favour of a tendency towards higher stone contents. Could Mr Leaver suggest any reason why higher stone contents are not more generally used?

It seems to be admitted by most authorities that the use of precoated chippings is purely for psychological effect on drivers, who feel that they are less likely to skid when they see some stone, whereas it also seems clear that in fact there is more danger of skidding when chippings are used. Figs 19 and 20 in Mr Leaver's paper show clearly how even a thin spread of chips completely breaks up the asphalt surface and, to a large extent, eliminates the contact of tyre with the bitumen–sand matrix.

Dr A. R. Lee: The comparison between the properties of concrete and those of asphalt is very interesting; the stiffness characteristic, which has now been suggested, is a form of Young's Modulus which is modified by the viscous flow which will occur if the deformation is carried on over a period of time. One might say it might correspond to one of the methods of measuring the Young's Modulus of concrete. There are two methods. One is an extensometer method, where one does stress the concrete and a steady load and measures its deformation. There is another way where it is measured by the vibration method; one measures its natural frequency of vibration, and from the dimensions of the specimen, one calculates a Young's Modulus. That method always gives a different answer from the extensometer method, the difference being that, in the extensometer method, one has a certain degree of flow taking place in the concrete, and the stiffness of asphalt is a property which might correspond to that property of concrete. Incidentally, we are ourselves developing a method to measure a Young's Modulus of bitumen by the vibration method, so that we will then be able to compare concrete and bitumen under identical conditions, in which flow will not take place.

As regards the strength, I would agree on Mr Bourne's conclusion. In fact, some years ago, we made up specimens of what we called in those days asphaltic concrete, and pitch concrete, and we found that their strengths, when we were testing in the normal way in which one would measure the strength of concrete by a transverse beam, were comparable, and in fact higher than the strengths of a strong concrete. That is to say if they were measured at temperatures and speeds of loading so that flow was not taking place during the testing. The difference is that the asphalt is temperature dependent, which will generally introduce flow characteristics that vary according to the temperature of test.

As to why 100 pen bitumen or soft bitumen is used for airfields, the Air Ministry must be asked the question. It is a question of development. In the early days, when deformations were not so important, they started with these softer bitumens and high stone contents. The specifications gradually developed and the bitumen has not changed.

As to the nature of the matrix of the asphalt, which corresponds to the matrix in the concrete, it is a mixture of fine aggregate or sand, filler, and bitumen. The filler and the bitumen are regarded as a medium which almost completely fills the voids in the sand, so as to give a dense plastic mortar.

P. C. Leaver: The first part of this question deals with gradings and, as I pointed out earlier, my view is that the important item of soluble bitumen content must be related to grading. Mr Bourne asked if I would confirm that it is possible to obtain an unworkable mix within the sand grading of B.S. 594. Whilst it may be true that a sand on the coarse end of the tolerances, with a bitumen content on the high end, would produce an unworkable mix, this is the nearest I can go to confirming the point, because the problem is more extended than just a consideration of the sand. For example, an asphalt containing a given percentage of stone may, under the terms of the British Standard, have such a wide scope in its grading range that the volume it occupies in the asphalt mass may also vary widely. Perhaps, therefore, I could say that it is possible to comply with the British Standard and yet produce an unsatisfactory asphalt.

As far as the comparison with concrete is concerned, there is an expression in the R.R.L. publication entitled *Concrete Roads* under "Design of Mixes" (Chapter 5, para. 5.4) which reads as follows: "The problem of designing a mix for a given purpose may be reduced in its simplest form to obtaining a concrete of the required strength and workability at the lowest cost by a suitable choice of materials and of the proportions in which they are used." I am not going to say that this can be done with asphalts, I am not sufficiently technically advanced, but in my opinion this should be the aim of the technical development of asphalt.

In regard to the selection of stone content, this is again based on experience. In wearing course mixtures for heavy duty on trunk road traffic, it is generally rare to go below 30 per cent of coarse aggregate, which might be described as a medium stone content. However, I have noticed that in the North of England, where a mix based on 25 per cent stone taken from the middle schedule of B.S. 594 is widely used, waving of a periodic kind occurs in a short time, in spite of the surface being laid to $\frac{1}{8}$ inch in 10 ft.

I agree with Mr Bourne on the use of precoated chippings. Although I have illustrated the specified rates of spread, my experience has generally been that when an attempt is made to get down to the thicker applications, the engineer has found the finish unacceptable and has requested that the chippings be applied at a thinner rate.

Dr A. R. Lee: I would like to ask Mr Leaver a question on the technique of manufacturing rolled asphalt. It has always struck me as a little peculiar. It is necessary to finish up with a mixture of coarse aggregate, fine aggregate, and bitumen in well-defined proportions. The asphalt contractor buys the stone and the sand to particular gradings; he feeds them together into one drier in very approximate proportions, where they become mixed together. Then he has to pass them through a bank of sieves so as to separate them back into the two materials of stone and sand in order that he can proportion them into his mixer.

It seems that there is a doing and an undoing process here. The contractor starts off with two materials which he wants in his final asphalt; he mixes them together for the purpose of heating and drying them, and then he has to separate them again in order to weigh out the required proportions for the final asphalt. It seems a complicated way of putting those two materials together to give the right proportions for the final mixture.

P. C. Leaver: The important point is to have some positive control over the proportioning of the aggregates, and it is difficult to see how else this can be done except by the present method. The only other system involves the use of separate dryers for stone and sand. Any advantages which arose from this would soon be lost under practical conditions, particularly if several sizes of stone had to be fed into the plant, as presumably this would mean a battery of dryers.

Dr H. N. Davies: Could the authors say whether rubberized bitumen, and asphalt made from it, have been used for roads in other parts of the world, and, if so, what proportion of rubber has been applied?

J. H. Nicholas: Generally speaking, anything between about 1 per cent and the economic limit has been used, the economic limit being usually of the order of 5 per cent. We have gone up to 15, but it can only be justified on special occasions. We still are not convinced, except on special occasions, that it is a major advantage to put the rubber in.

P. C. Leaver: I have had something to do with the use of rubber in bitumen. One of the things that impressed me during an experiment we were doing was that we used what seemed such a small amount of powdered rubber that it could not possibly make any difference, because it was only 2½ per cent of the bitumen content. This small amount of powdered rubber was put into the bitumen, and when it was drawn out in a thread it was possible to stretch it nearly across a room. I am not going to advance any technical views on its use, but I was very impressed with the effect it made on the bitumen.

H. G. Barnes: I would refer to a point in Mr Leaver's paper with regard to the finished profile of the asphalt. He referred to the tediousness of using a straight-edge to check the profile, as is actually required by the British Standard. I feel that the general standard with which rolled asphalt is finished as regards riding quality is often very poor. Recently a base on which asphalt was to be laid was tested with a multi-wheeled profilometer and we obtained a q value of 60, which is quite good for a base. The asphalt was laid, and was tested again, and the q value was 120. That means it was twice as bad as the base. One can go about the country and see a lot of places where a very bumpy new asphalt has been laid.

Mr Leaver refers to the possibility of towing a profilometer behind the Barber-Greene machine. That would be between the Barber-Greene machine and the roller, otherwise it would interfere with the rolling operations. It would seem that although the Barber-Greene may leave the surface of the asphalt very regular, the regularity may be spoilt by the action of the roller. So that what is really wanted is a profilometer behind the roller.

I would also like to ask Mr Leaver whether he has has experience of a three-axle roller, which was used in the U.K. many years ago, but has been used a lot more in the U.S.A.

Mr Leaver spoke of the need for an increased output on mixing plants to keep in step with the laying plants, which leads to the question of how long he mixes the material. How does he judge the mixing time necessary?

P. C. Leaver: In asphalt construction I always try to get personal experience of such jobs as using a straight-edge, so that it is possible to know exactly what can be achieved when directing men. It was on this basis that I commented on the present methods, particularly on large-scale construction.

The suggestions for a mechanical method of testing the accuracy of a finished surface were based on two reasons. First, as it is a manual method I turned my mind to whether it could be done by machine. Whilst it is true that the roller can still affect the surface, I do not think any faults in the rolling technique will produce such band effects as poor control of the spreader. In any case, when the roller has passed it is usually too late to do anything to the surface. Secondly, I feel that if straight-edge control is provided mechanically or automatically, it does at least reduce one variant in the problem of producing an accurate running surface.

I certainly agree with Mr Barnes that the standard of laying in the U.K. requires looking at very carefully. I think we are going to have rather a shock if we ever get to the stage of motor-way construction, as I believe that some of the possible average speeds come within the range of 30–40 m.p.h. for heavy loads and 60 m.p.h. for private vehicles. I have found that when there are variations from the tolerances in the British Standard it is very noticeable under speed. It is also distinctly possible that these tolerances will not be adequate for the future.

I have had no experience of the three-axle roller. At the recent Road Show I was informed that it was not available in the U.K.

I have no means of judging how long a mix should remain in the mixer other than my own experience. However, we have modified some of our mixers on the lines of Road Note 21, and this has assisted considerably in producing a uniform mixture.

A vote of thanks to the three authors was accorded with acclamation.

OBITUARY

RICHARD STANSFIELD

1891–1957

RICHARD STANSFIELD, a Fellow of and prominent in the Institute since he was elected in 1931, died at his home at Walton-on-Thames on 28 June 1957; his loss will be felt deeply by the many friends he made during a very active life. His major technical interest was research on the behaviour of internal combustion engines, and there is scarcely a facet of this very wide subject to which he has not made an important contribution.

From 1914 to 1919 he was responsible for the testing and installation of diesel engines in submarines built by Sir W. G. Armstrong Whitworth & Co., Newcastle-on-Tyne. Later, in 1919, he became test department manager of the gas and oil engine department at Scotswood works; and in 1922 he was transferred to the London office as sales manager (technical) of the same department.

He joined the Anglo-Persian Oil Co. Ltd (now The British Petroleum Co. Ltd) in 1926, and was commissioned to start an engine research laboratory which, from small beginnings, he was able to see grow under his direction into one of the finest establishments of its kind. In 1936 he was appointed Chief Research Engineer to the Company.

His early work for the petroleum industry was in connexion with the knock rating of motor gasolines in the period prior to 1930, followed by a series of visits to the U.S.A. in the early thirties. In 1932 he participated in the Uniontown road tests on which was based the CFR Motor Method octane number determination; and this started a close personal co-operation with his counterparts in the U.S.A.

He was one of the first to realize the significance of the ignition quality of diesel fuels, and his pioneer work in this field has been presented in several papers to this Institute and other bodies.

In 1934 he started the development of a cathode-ray oscillograph engine indicator which has found wide application since it was made generally available in 1936.

During the period 1938–41 he was actively engaged in the development of a rich mixture test for aviation fuels, and his work contributed largely to the adoption of the CFR Supercharged test by the Western Powers. His foresight in this field played no small part in enabling the production of 100 octane aviation gasoline at Abadan refinery to be built up to the very high level demanded by war needs. Another war-time activity was the development of apparatus for measuring torsional vibration in high-speed engines, which proved to be of considerable value to the Admiralty. He was also a prominent member of Ministry of Aircraft Production Committees.

His post-war work was largely concerned with the development of lubricating oil test procedures. He retired from The British Petroleum Co. Ltd in December 1952, and became consultant to the Admiralty in setting up their Oil Laboratory. He retired from this position in June 1955 and became honorary consultant.

Dick Stansfield will be remembered by his colleagues and staff particularly for his personal qualities. His kindly, inspiring, and yet forceful personality made him a true leader, and there are many who owe him a great debt for the help and encouragement they received in the building of their careers. In the Committees of the Institute and in the Institute as a whole he will be remembered for his boundless energy and enthusiasm, and for his cheerful and forthright approach, which made him so many friends on both sides of the Atlantic.

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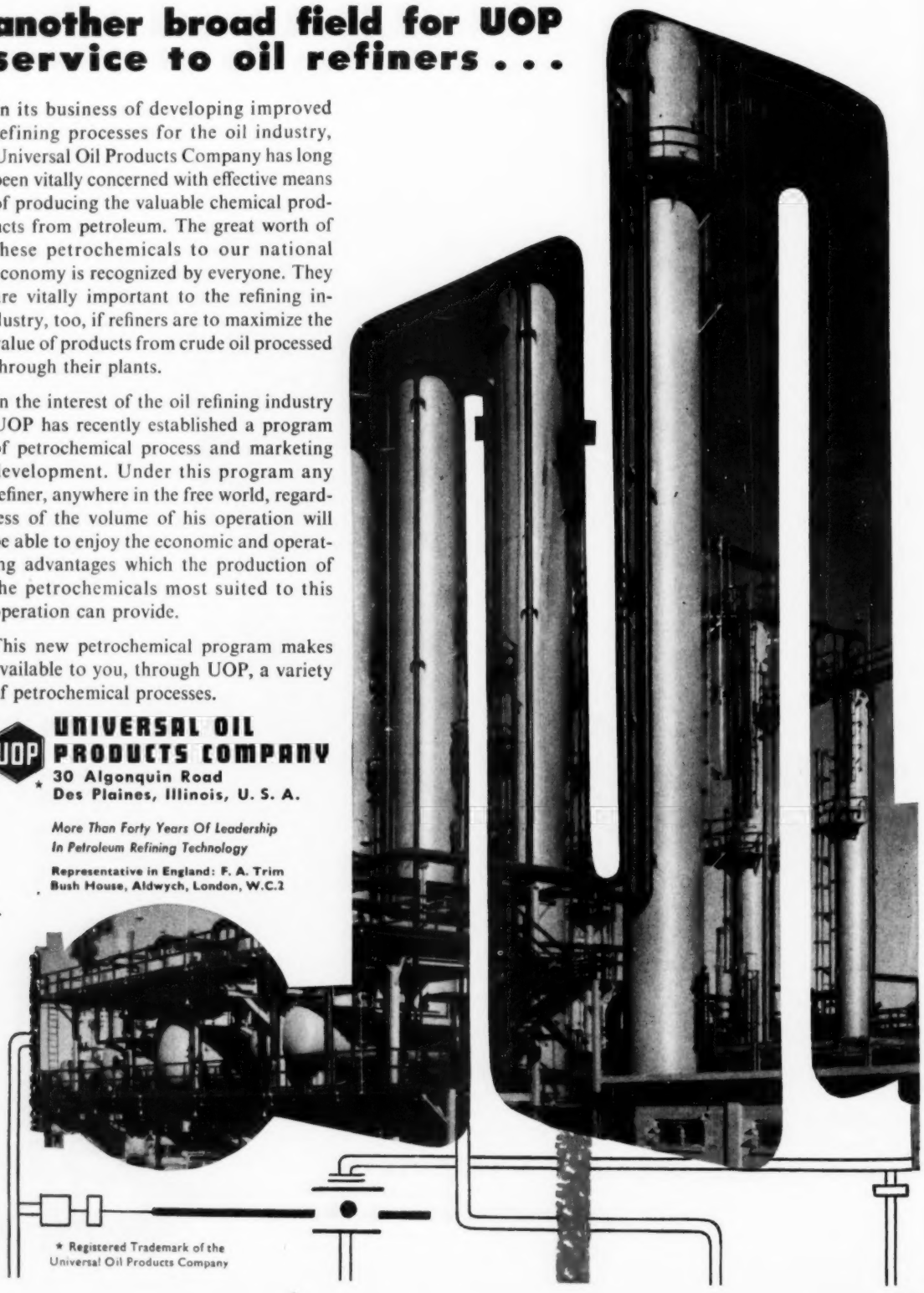

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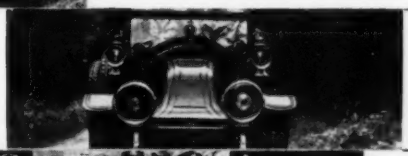

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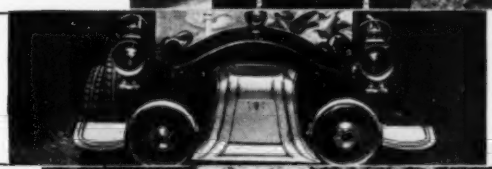

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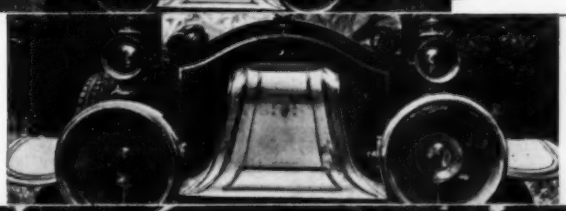

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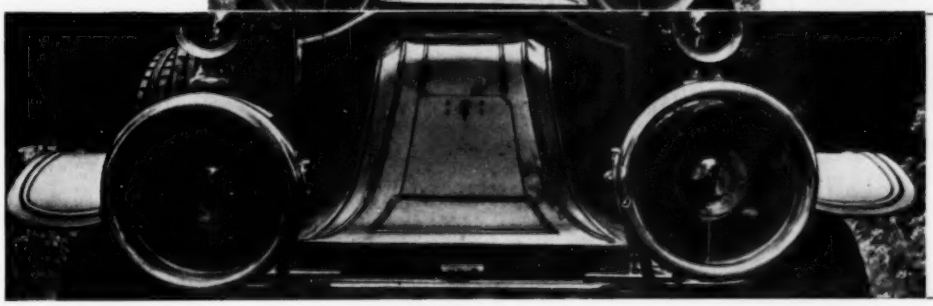

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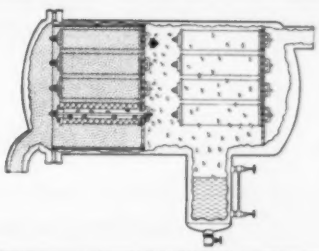

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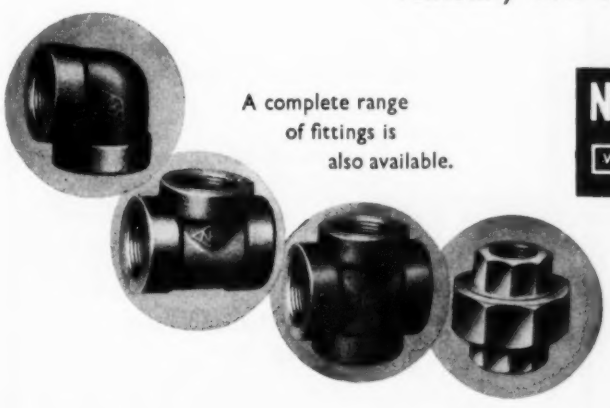

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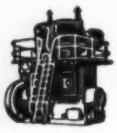

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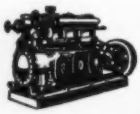

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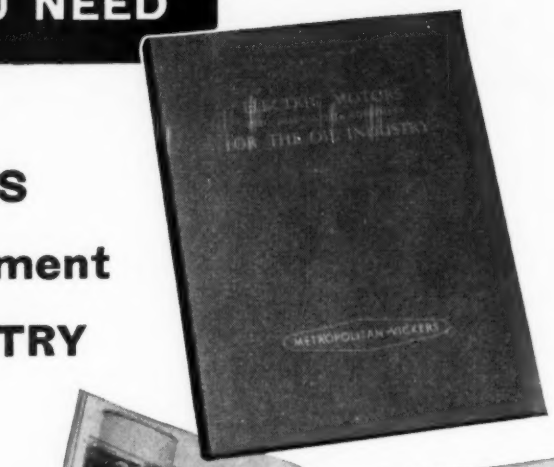

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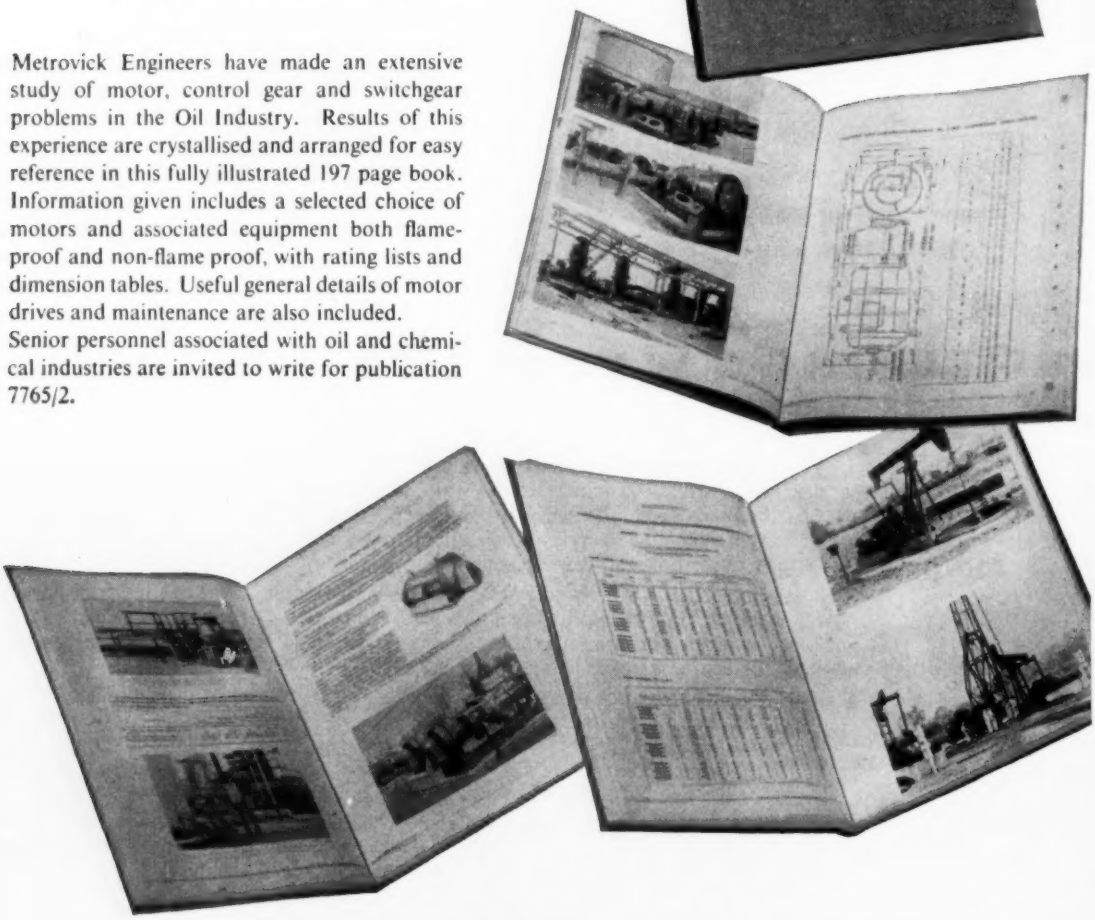

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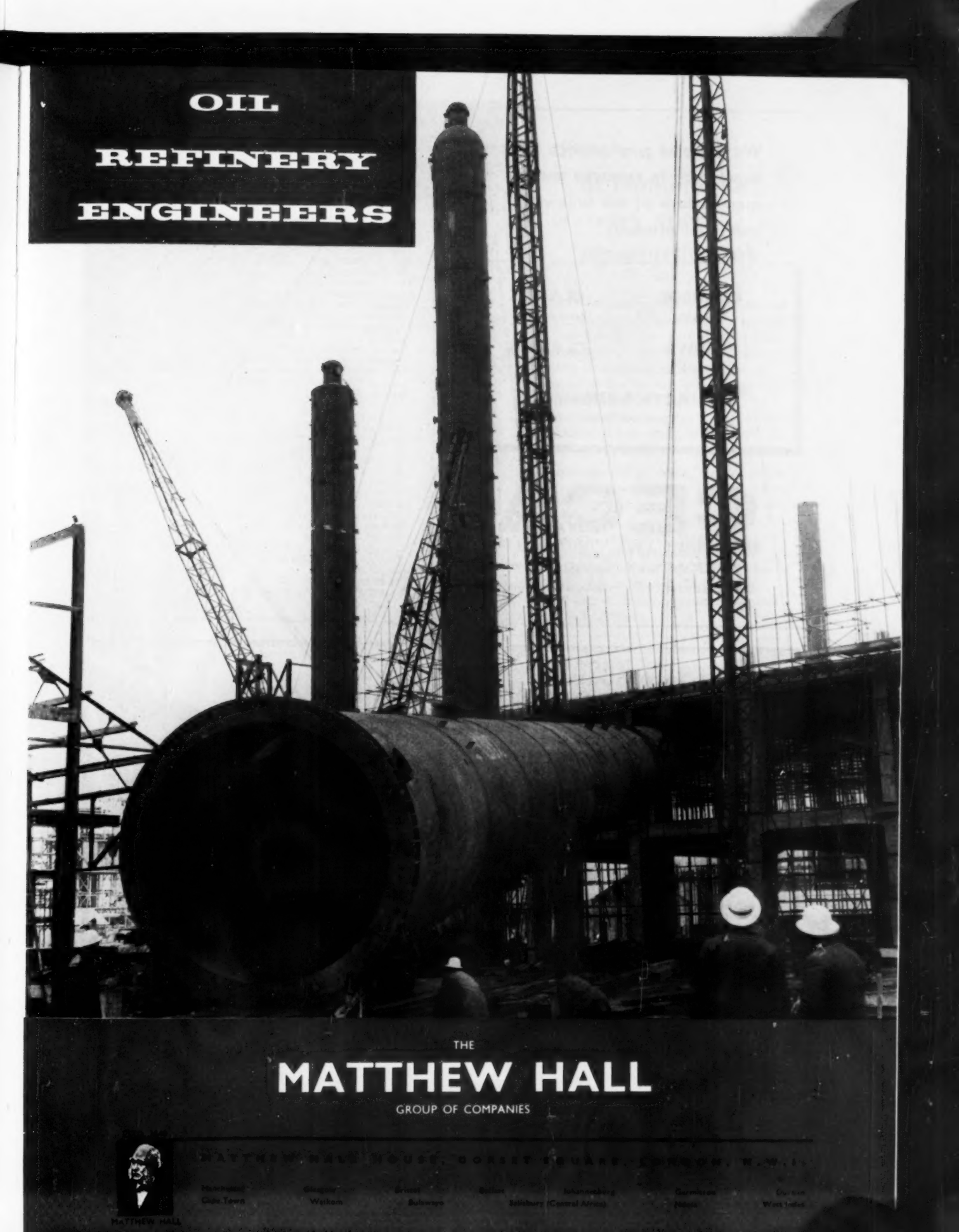

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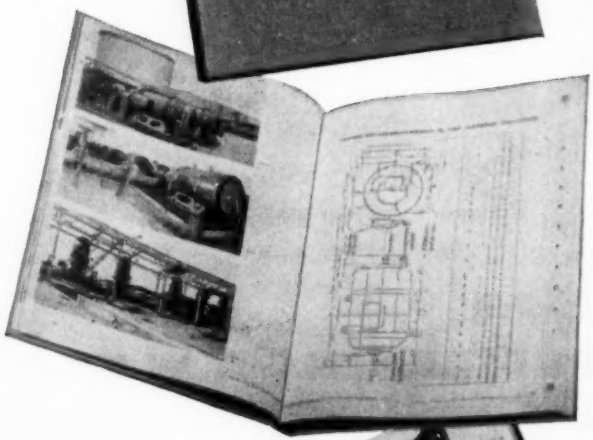

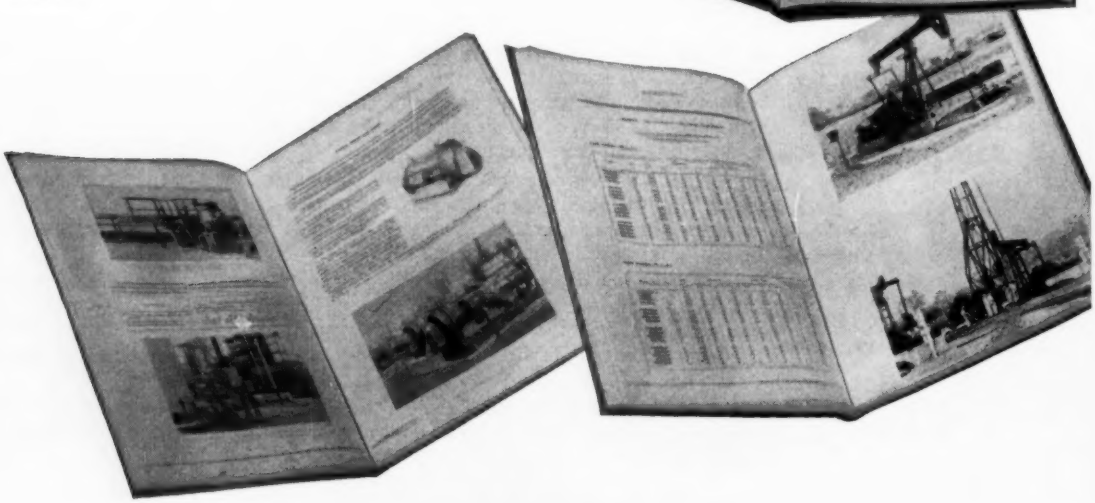

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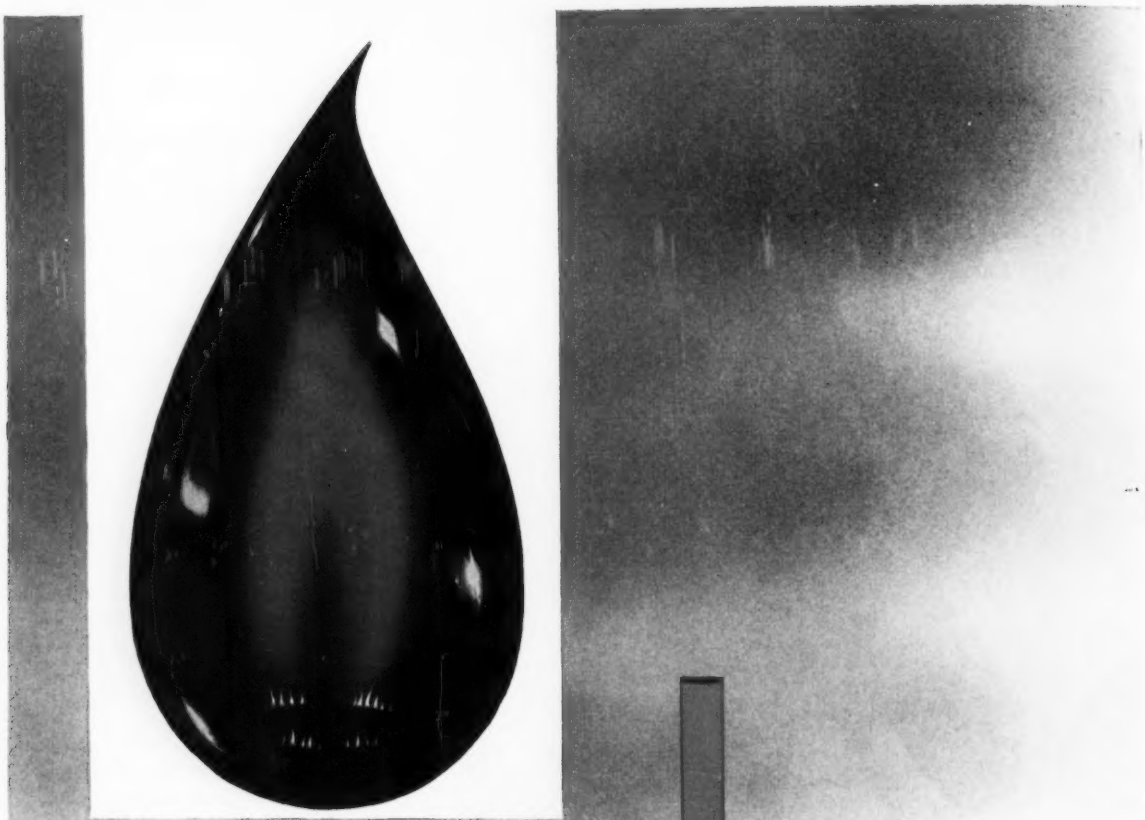

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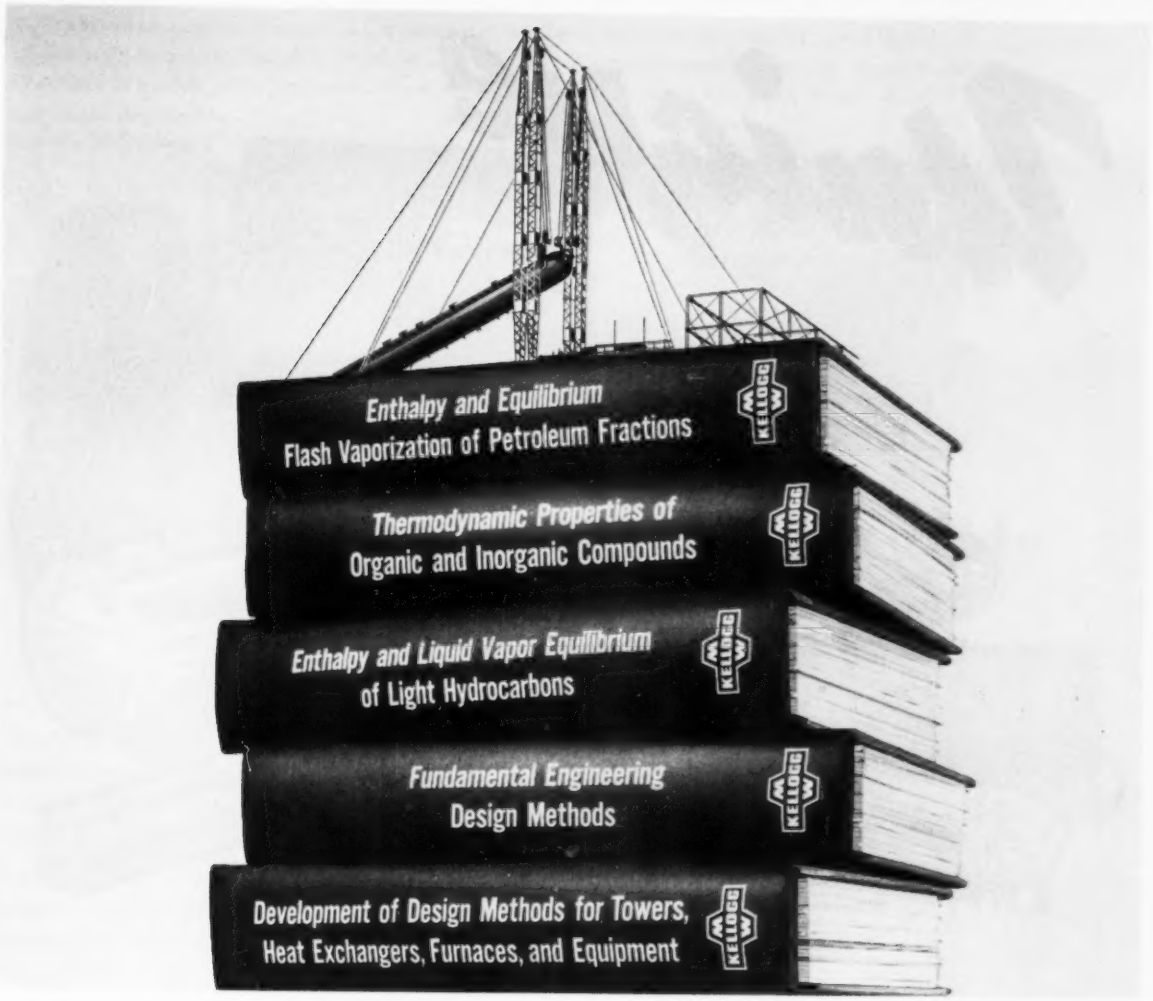

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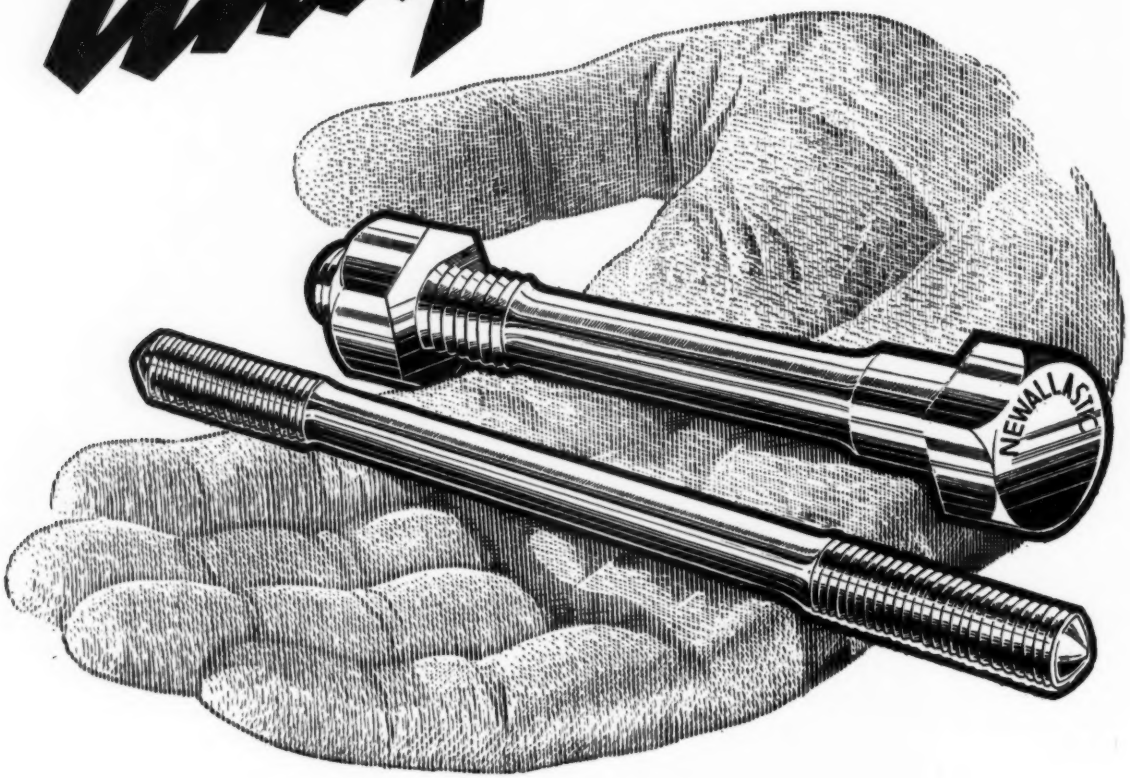

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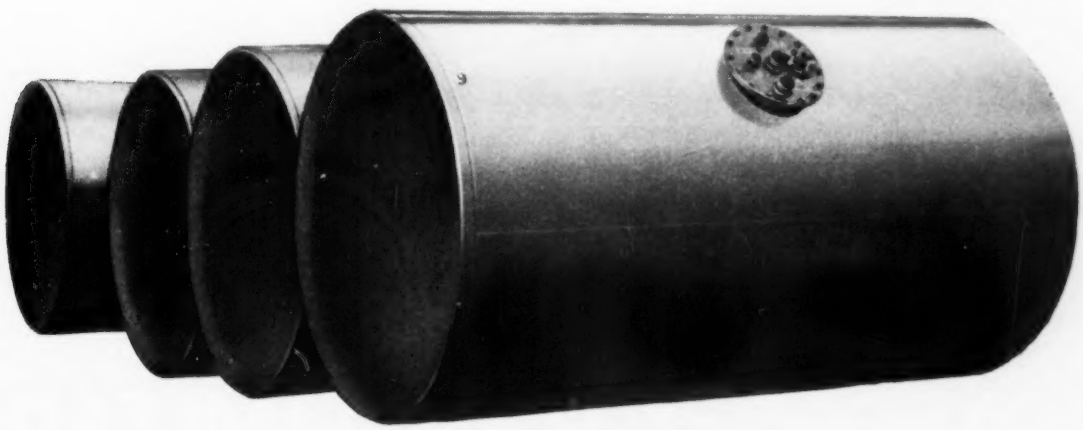

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